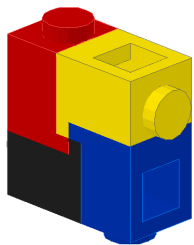
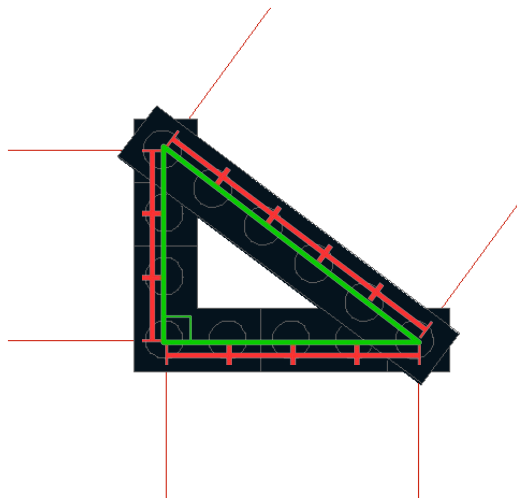
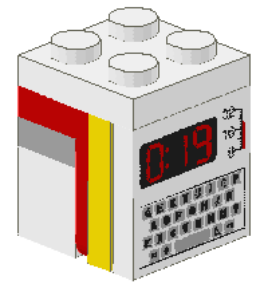


Brick Geometry

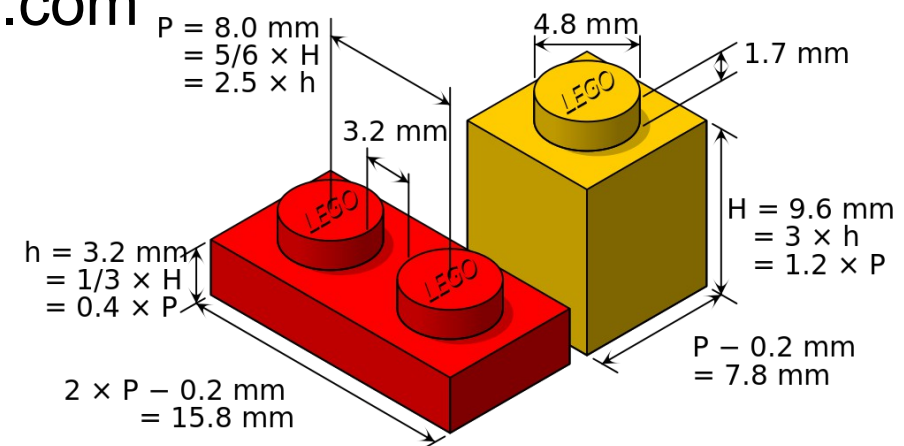
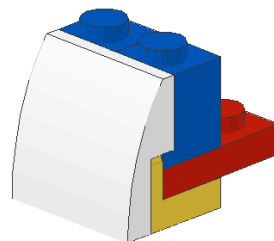
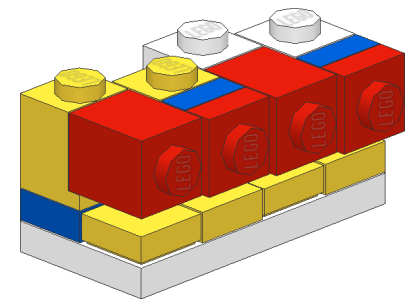


Bricks by the Bay 2018
Santa Clara, CA



Bill Ward

bill@wards.net
www.brickpile.com



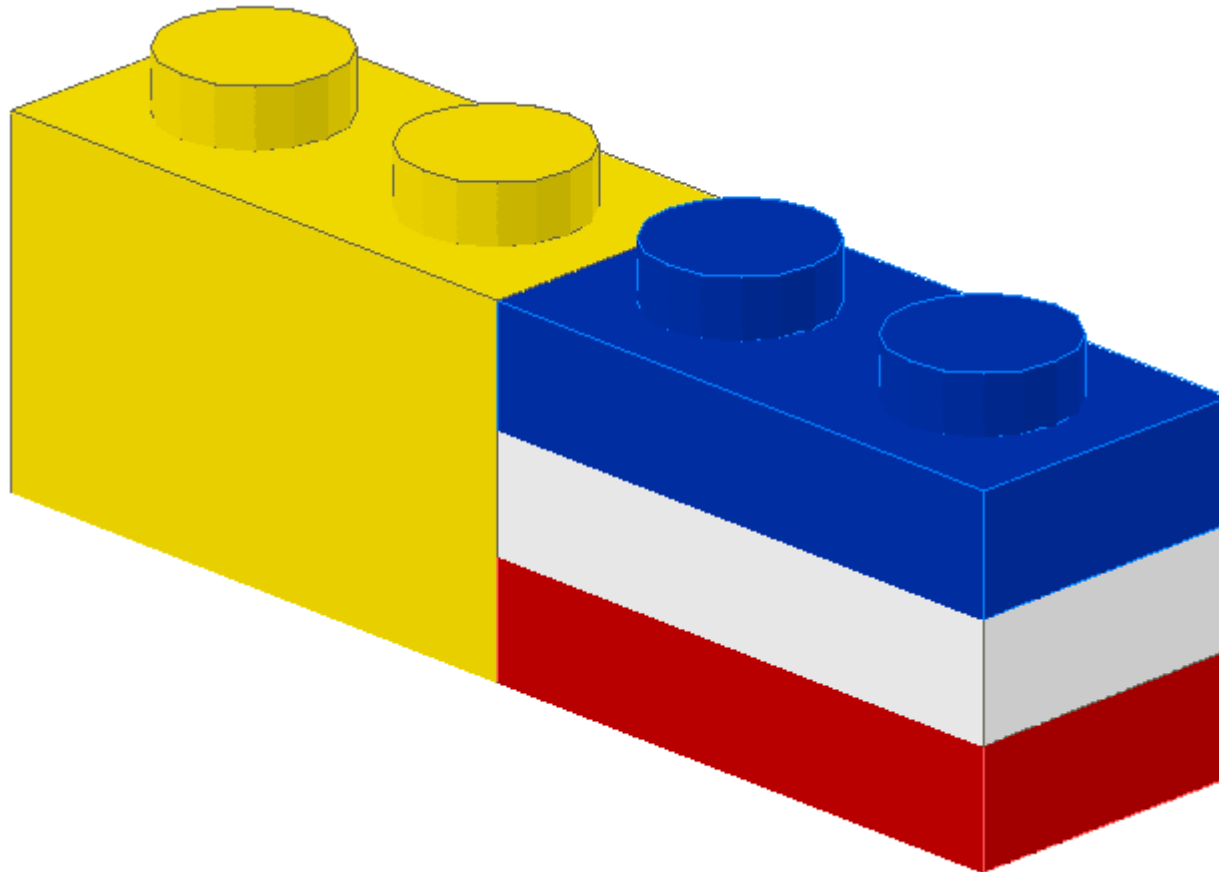


Ratios and Dimensions

Basic LEGO Geometry

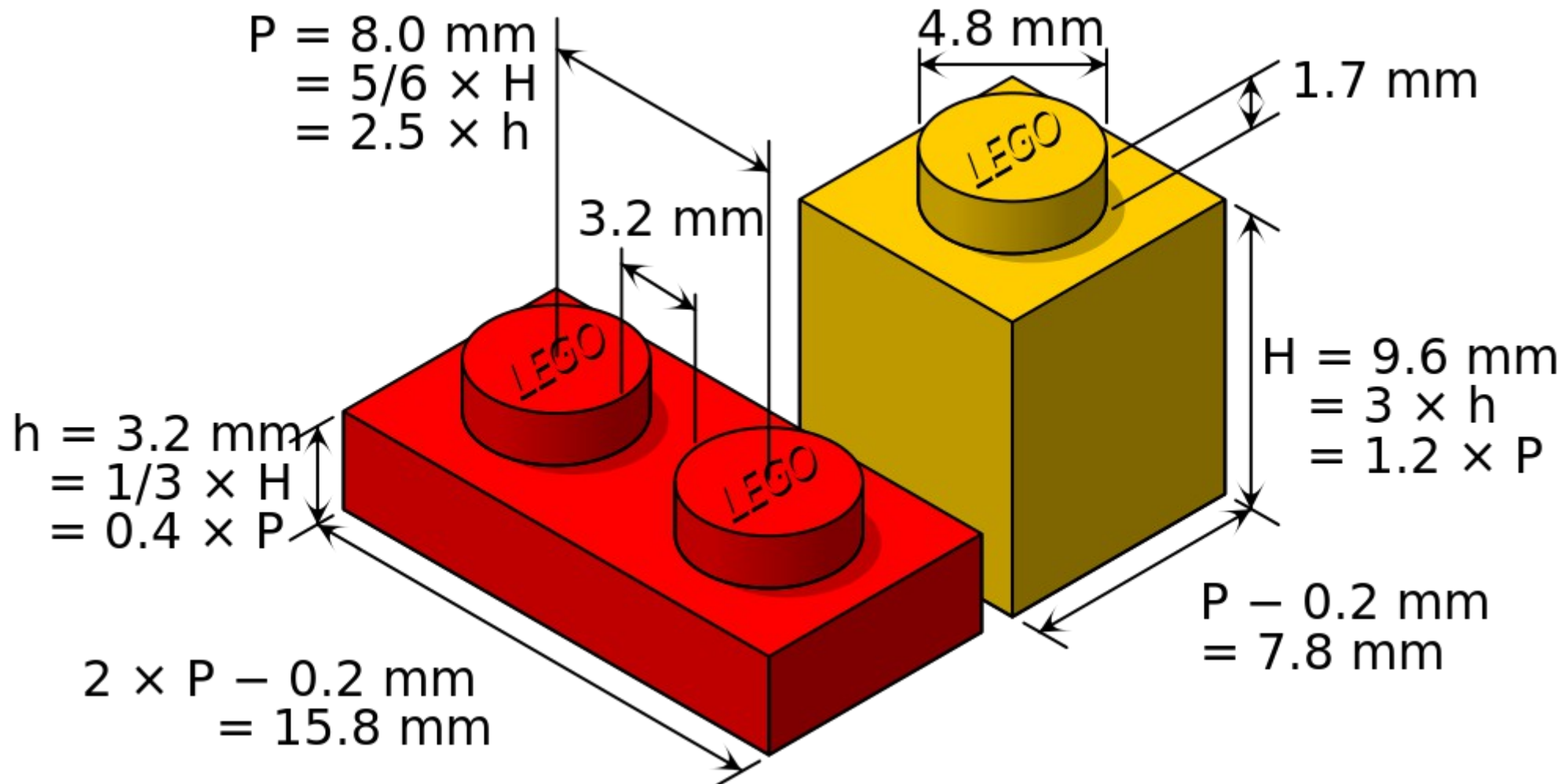
1 brick = 3 plates

Everyone knows this, I hope...



LEGO Dimensions

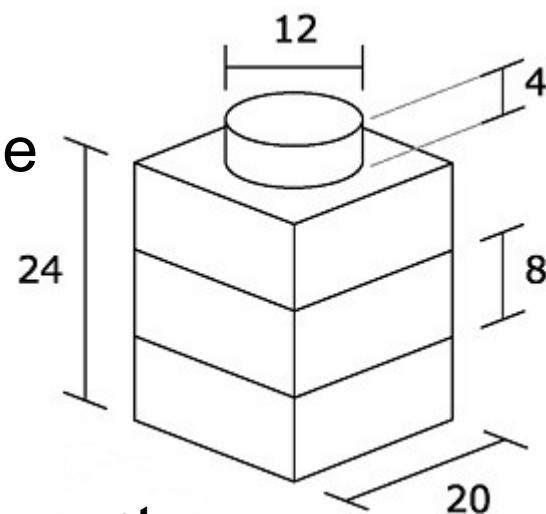
Quick! Memorize all these numbers. There will be a quiz later.



Math is Hard!

LDU = LDraw Unit

- A 1x1 stud brick or plate is $\frac{5}{16}$ " or 8mm (0.8cm)
- The height is $\frac{6}{16}$ " or 9.6mm (0.96cm)
- To make the math easier, LDraw designers came up with the LDraw Unit (LDU)
- Everything is a nice, easy integer this way!



	<u>LDU</u>	<u>studs</u>	<u>bricks</u>	<u>plates</u>	<u>cm</u>	<u>inch</u>	<u>pt</u>
LDU	1	1/20	1/24	1/8	0.04	1/64	9/8
studs	20	1	5/6	5/2	0.8	5/16	45/2
bricks	24	6/5	1	3	0.96	6/16	27
plates	8	2/5	1/3	1	0.32	2/16	9
cm	25	1.25	1.04	3.125	1	0.39	28.3
inch	64	3.2	8/3	8	2.54	1	72
pt	8/9	2/45	1/27	1/9	0.0353	1/72	1

LEGO Bricks Are Not Square

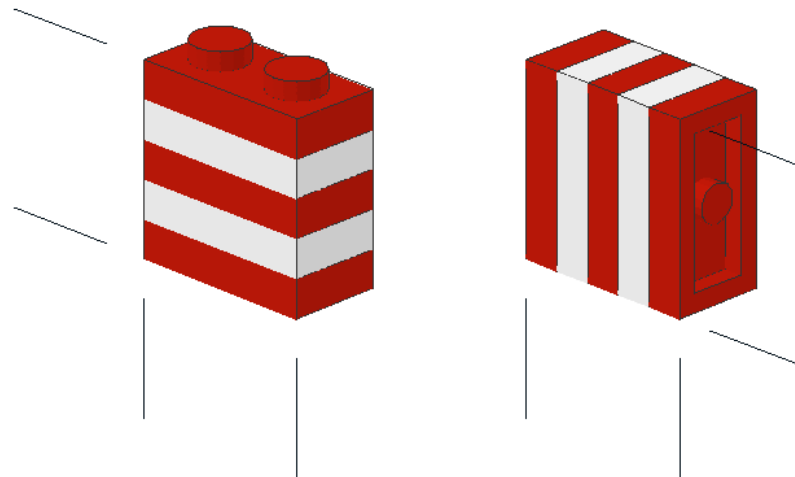
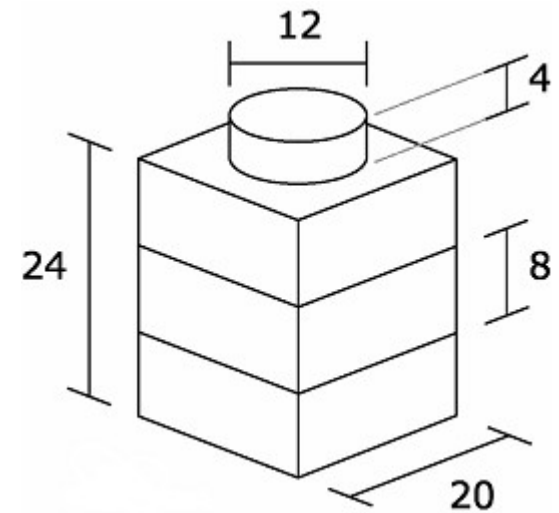
Bricks are 8mm wide by 9.6mm high

How do you make widths and heights match?

LDU makes the math easy....

How many plates = how many studs?

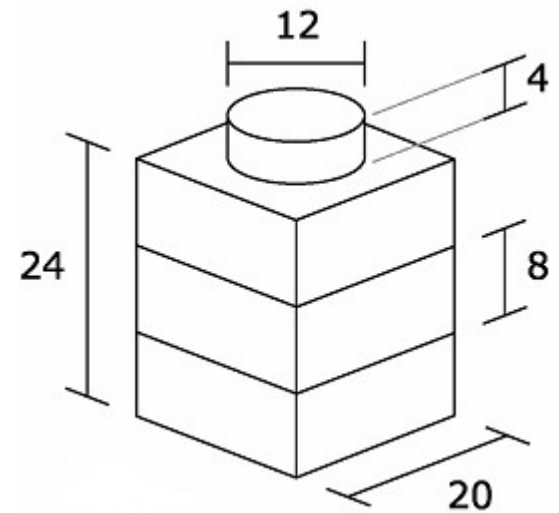
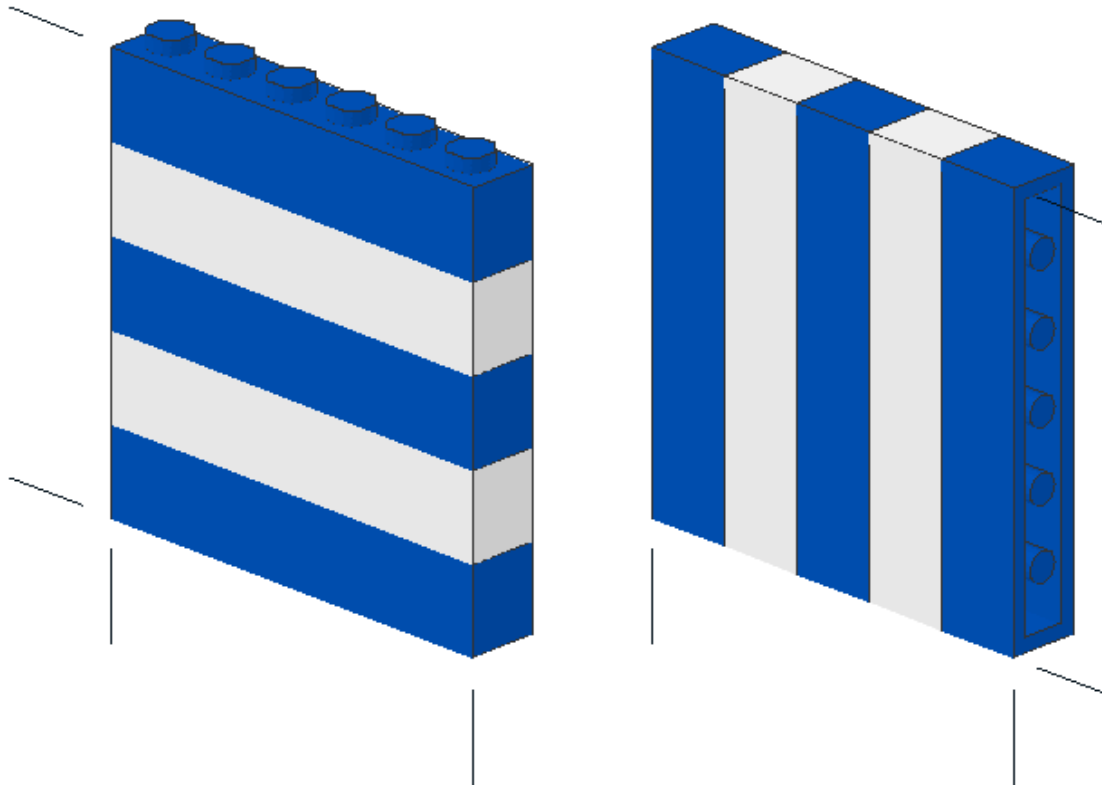
- 2 studs = $2 \times 20 = 40$ LDU
- 5 plates = $5 \times 8 = 40$ LDU



6:5 Brick Ratio

How many bricks = how many studs?

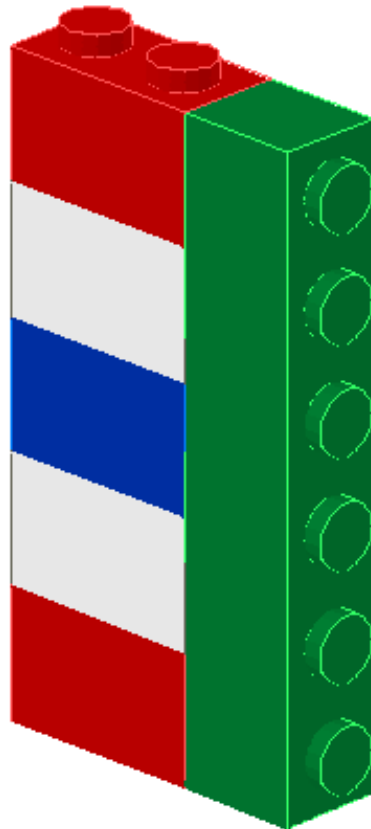
- 6 studs = $6 \times 20 = 120$ LDU
- 5 bricks = $5 \times 24 = 120$ LDU



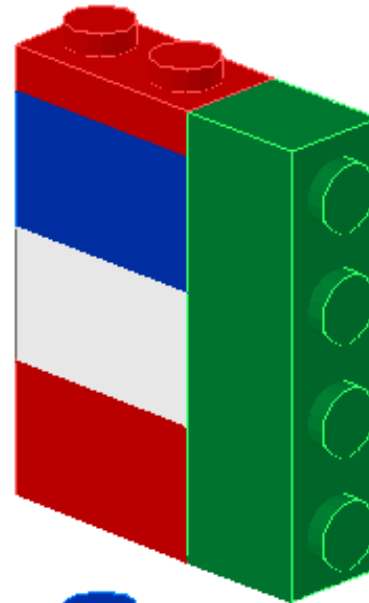
Even Numbers of Studs

Any even number of studs corresponds to a combination of bricks and plates, since $2 \text{ studs} = 5 \text{ plates}$

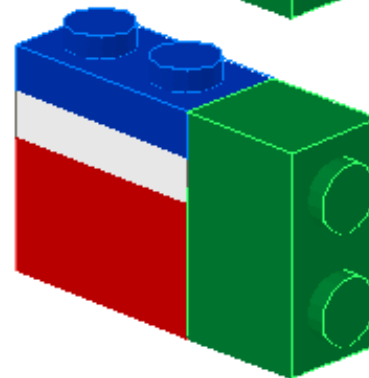
6 studs =
5 bricks =
120 LDU
(or 15 plates)



4 studs =
 $3 \frac{1}{3}$ bricks =
80 LDU
(or 10 plates)

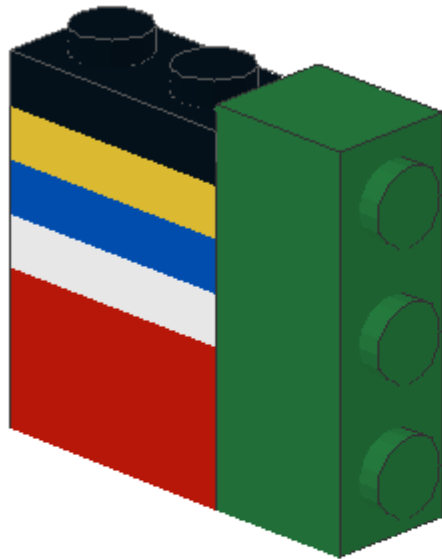


2 studs =
 $1 \frac{2}{3}$ bricks =
40 LDU
(or 5 plates)



Odd Numbers of Studs

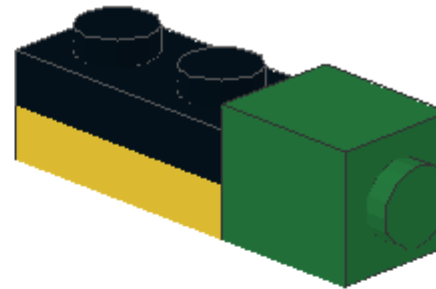
Since 1 stud = $2\frac{1}{2}$ plates, no combination of plates adds up to exactly one stud



3 studs = 60 LDU

1 brick + 4 plates = 56 LDU

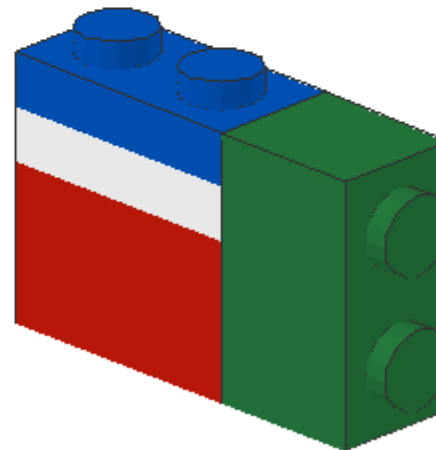
?? = 4 LDU
(Missing $\frac{1}{2}$ plate!)



1 stud = 20 LDU

2 plates = 16 LDU

?? = 4 LDU
(Missing $\frac{1}{2}$ plate!)



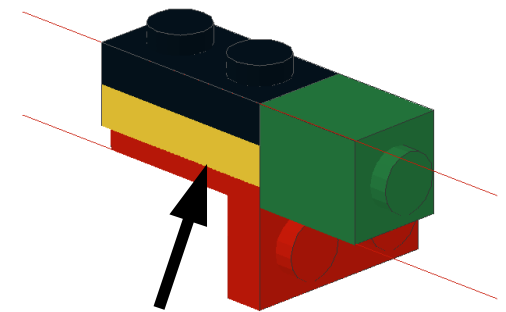
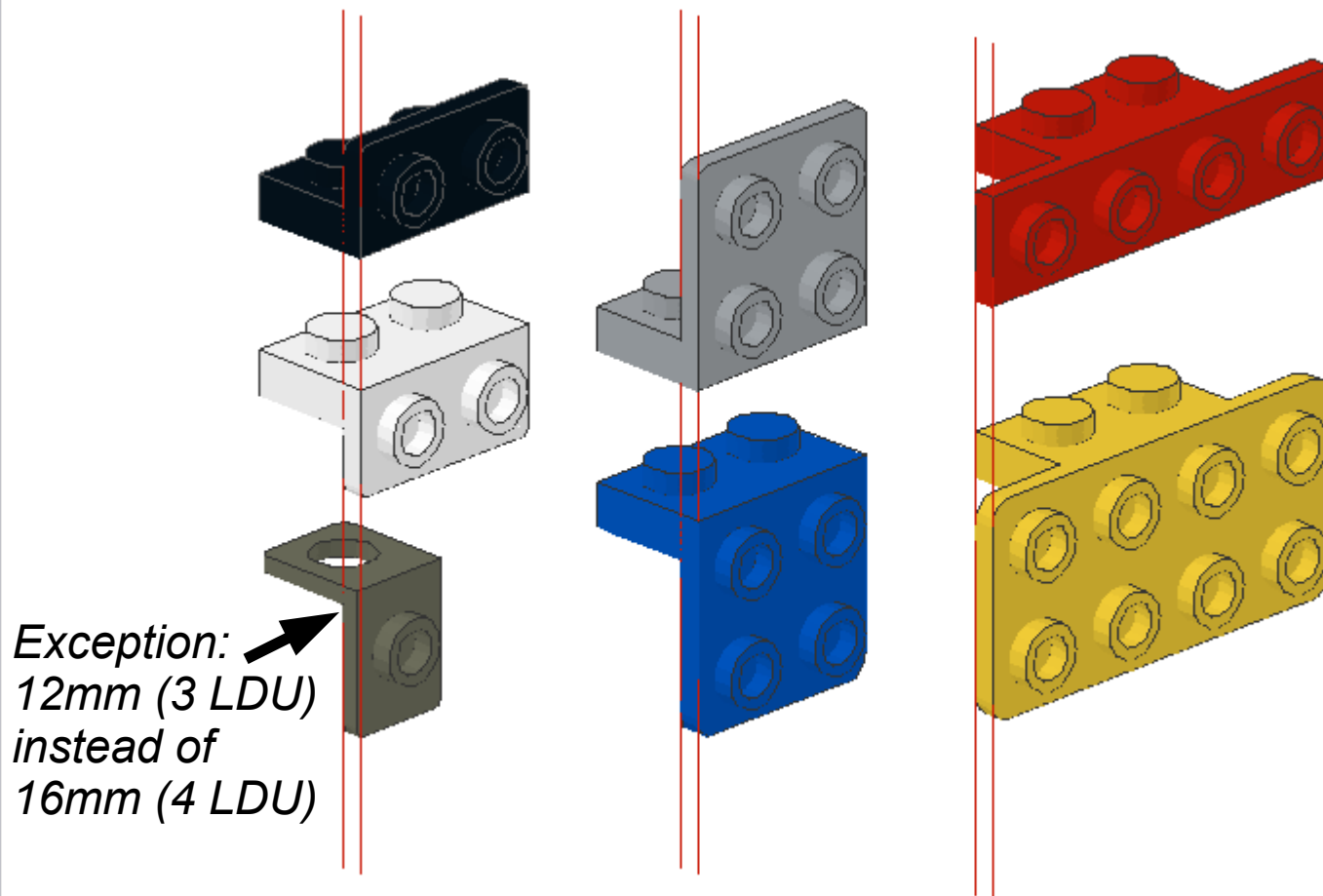
2 studs = 40 LDU

5 plates = 40 LDU

(OK)

But where do you get ½ plate?

One answer: brackets. The thin vertical plate is ½ the thickness of a normal plate, or 4 LDU

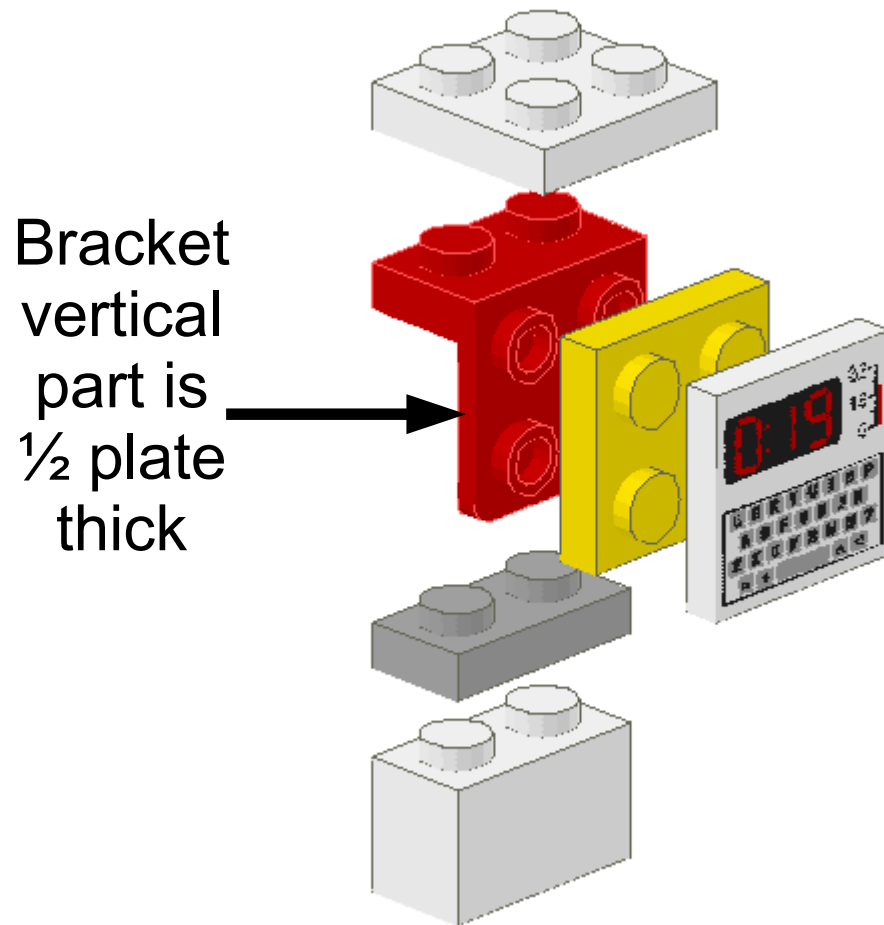


1 plate = 8 LDU thick
1 stud brick = 20 LDU
2 plates + bracket =
 $8 * 2 + 4 =$
20 LDU

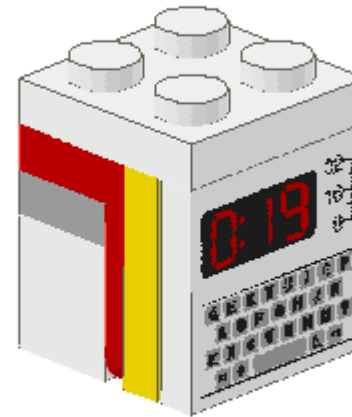


SNOT
Studs Not On Top

Using $\frac{1}{2}$ plate thickness from brackets



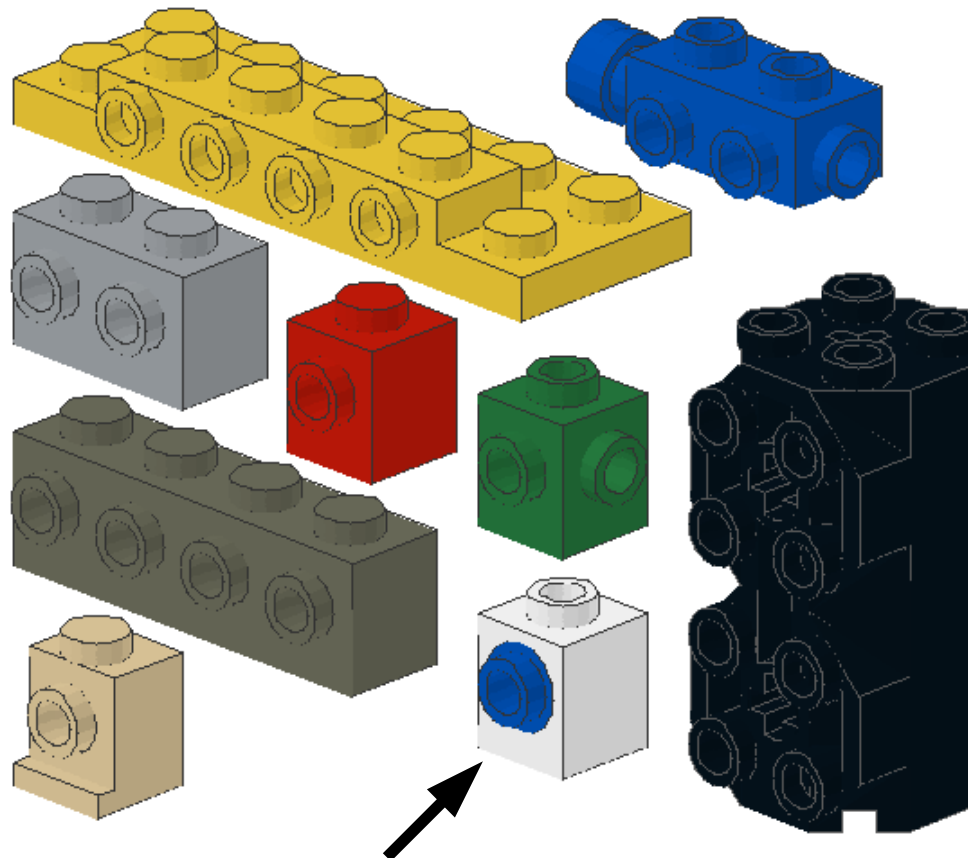
$\frac{1}{2}$ plate from bracket
+ 1 plate + 1 tile
= $2 \frac{1}{2}$ plates, same as 1 stud



Computer tile is
flush with edge
of white 2x2
plate.

Bricks with Studs on the Side

LEGO has plenty of parts that have studs on the side, useful for SNOT (Studs Not On Top) design, similar to the brackets.



** Technic brick with $\frac{1}{2}$ pin is not quite the same – see next page*

Caveat - Technic Pin Alignment



Technic pin hole placement is just a little higher (about 0.2mm) than stud-on-side placement.

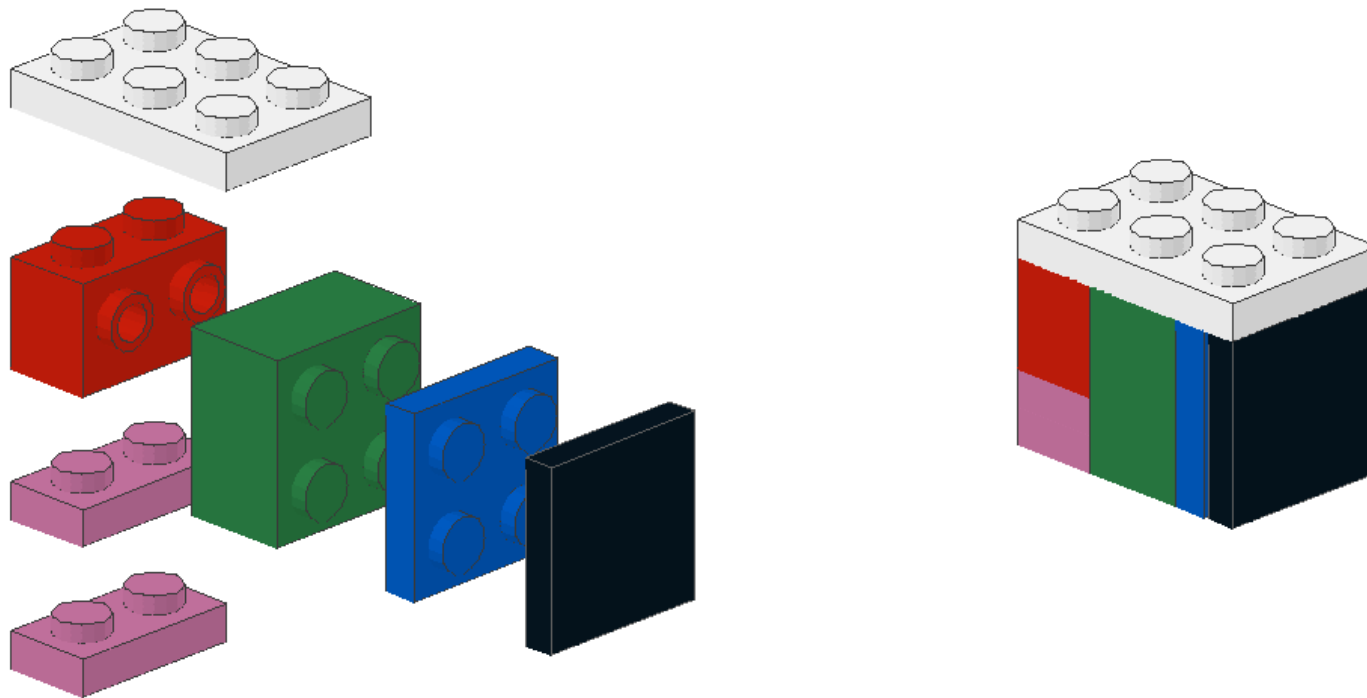
Some models may have alignment problems due to this.

Reason: early Technic brick molds needed thicker plastic between pinhole and bottom of brick.

Result: LEGO now produces more bricks with studs on side instead of using $\frac{1}{2}$ pins in Technic bricks – better for us anyway

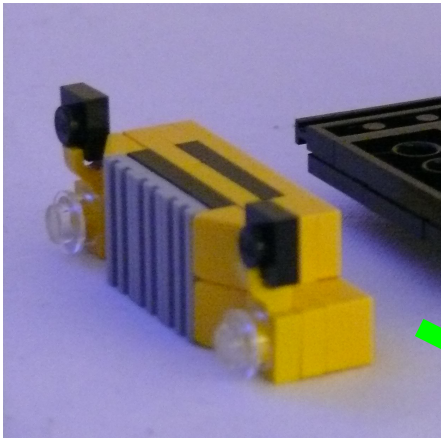
Bricks with studs on sides to mount flush

Use bricks with studs on sides to attach assemblies at 90 degrees.
To mount them flush, remember that 5 plates = 2 studs = 40 LDU.



Flush tile examples

My Lunar School Bus model used this technique.

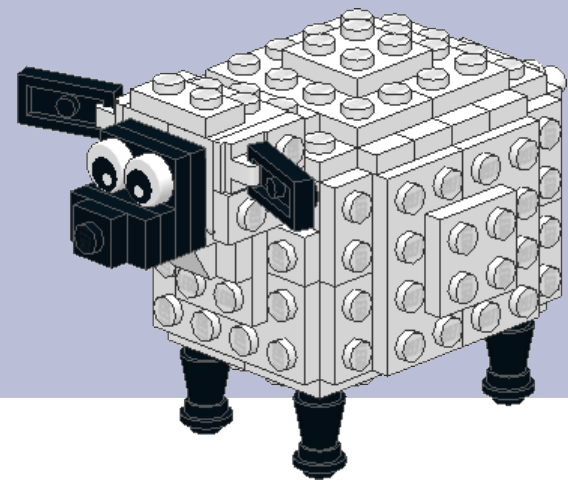


Grille and headlight
sub-assembly fits
flush in 2-stud space

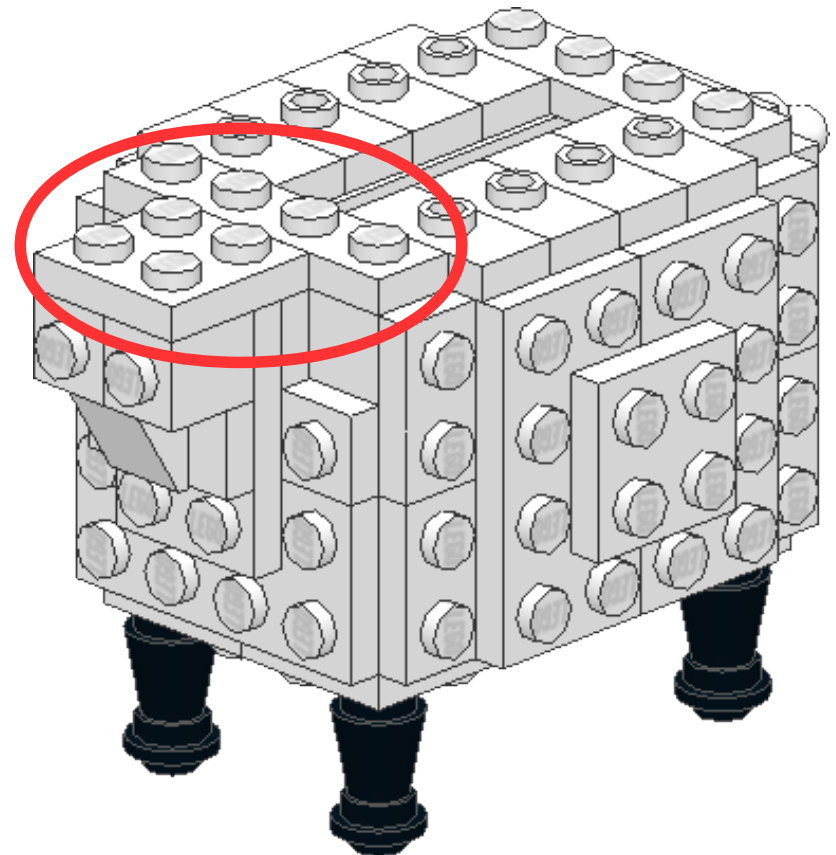
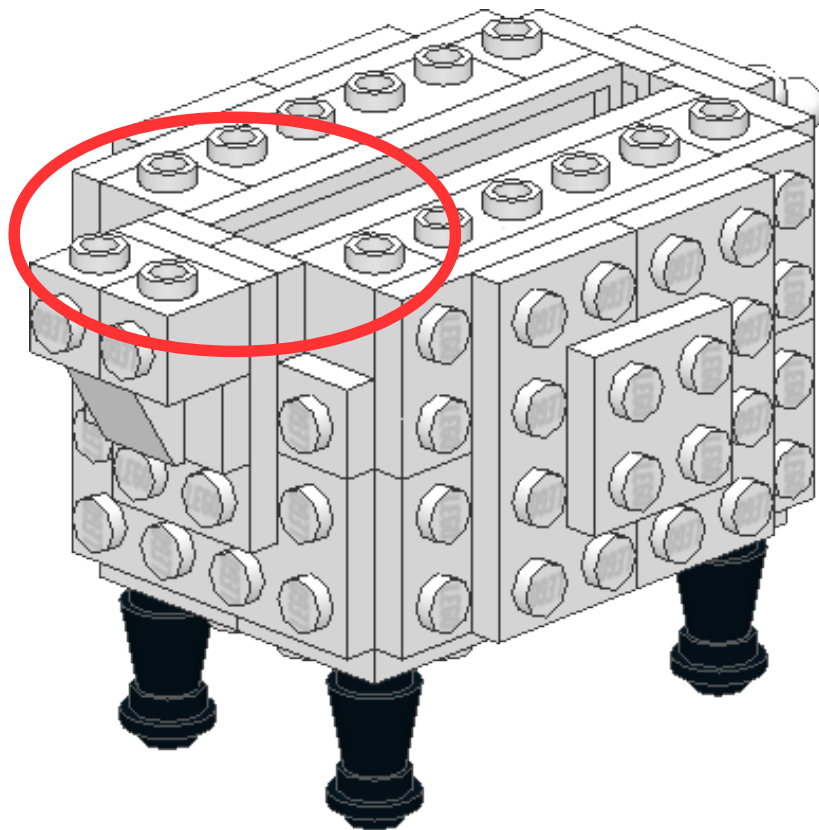
5 plates
= 40 LDU
= 2 studs



Another Alignment Example

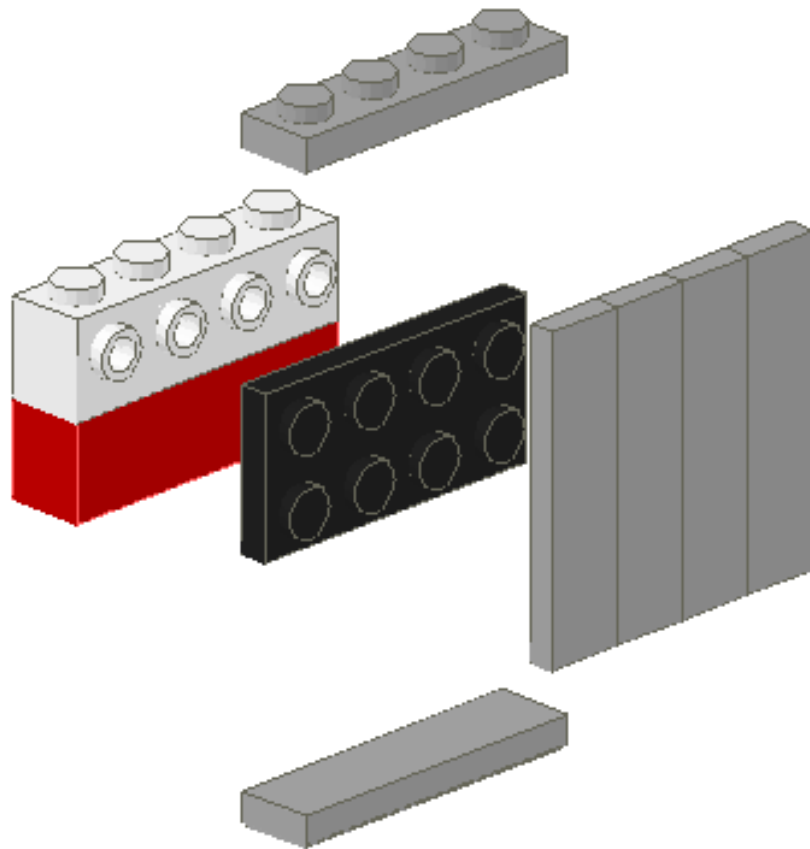


Note how the neck is made from a brick and two plates = 40 LDU
So we can place a 2x2 plate on top and the studs line up with the rest of the body

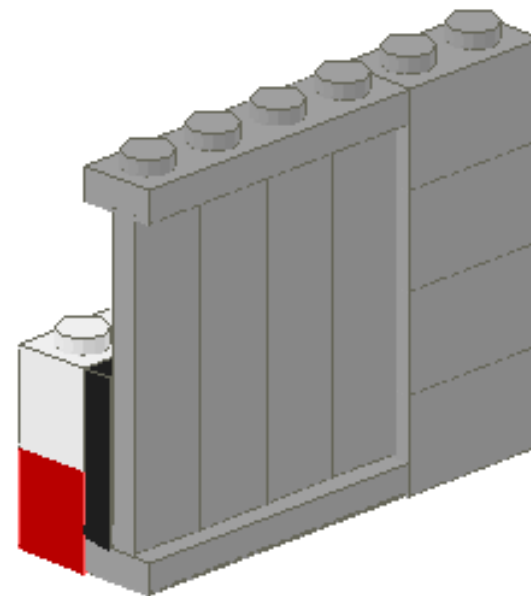


Inset Panels

Use half-plate offsets to add texture to an otherwise flat wall



1 plate + 2 studs (1 $\frac{2}{3}$ brick)
= 2 bricks



Tiles are $\frac{1}{2}$ plate inset

2 plates + 4 studs (3 $\frac{1}{3}$ bricks)
= 4 bricks

Inset panels example



Panels inset by 1/2 plate

My F40PH Caltrain locomotive

“De Vier Gekroonden”

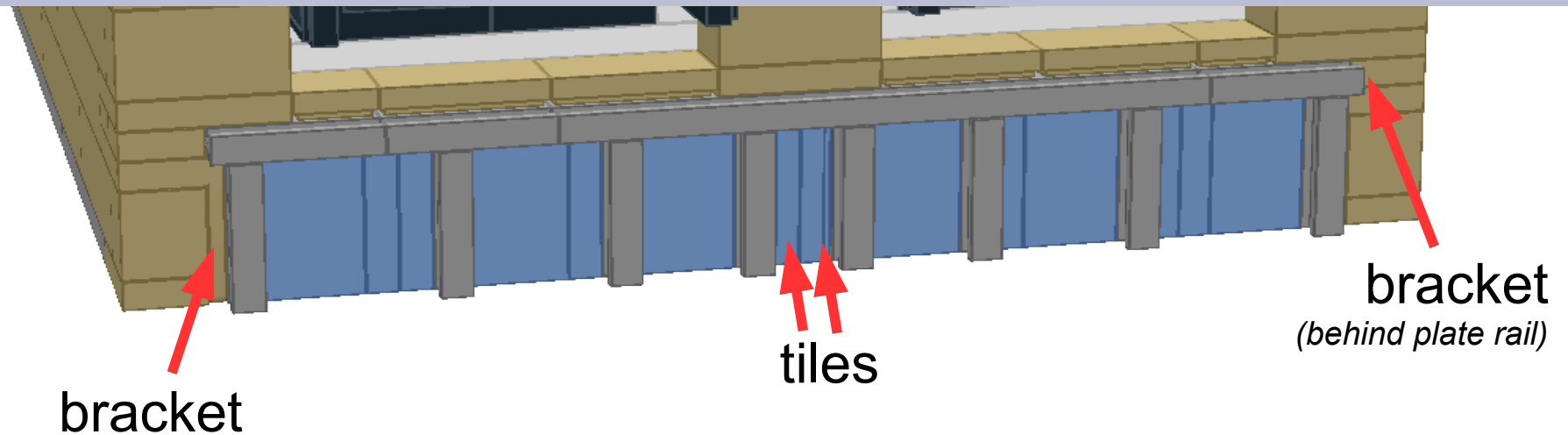
This model by Vincent
“Mr. Tomato Bread”
Kessels uses some of
these techniques.

Photos used with permission

Model:
“De Vier Gekroonden”
by Vincent Kessels
a.k.a.
“Mr. Tomato Bread”



Sideways Building with Brackets



Stack bricks and plates with a tile on the end

Mount on bracket on each side facing inward

$3 \text{ bricks} = 3 \times 24 = 72 \text{ LDU}$

$7 \text{ plates} + 1 \text{ tile} = 8 \times 8 = 64 \text{ LDU}$

$\text{bracket} = 4 \text{ LDU}$

$\text{Total} = 140 \text{ LDU} = 7 \text{ studs}$

Tiles on the ends press together and friction holds it all together

Model:

"De Vier Gekroonden"
by Vincent Kessels
a.k.a.

"Mr. Tomato Bread"

The Problem with Jumper Plates

Requirement: 5-stud wide window openings with 6-stud wide arches above.

Solution: offset the arches by $\frac{1}{2}$ stud using jumper plates

Side effect: How to fill $\frac{1}{2}$ stud gap on ends?

Imperfect solution: attach tile mounted sideways.

$\frac{1}{2}$ stud = 10 LDU. Tile = 8 LDU. Gap of 2 LDU ($\frac{1}{4}$ plate) cannot be filled by any LEGO part. Any better ideas to fill a 10 LDU space?

Model:
"De Vier Gekroonden"
by Vincent Kessels
a.k.a.
"Mr. Tomato Bread"

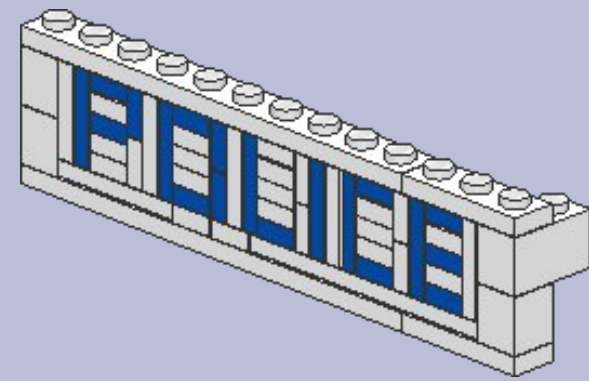


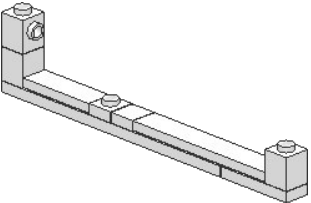

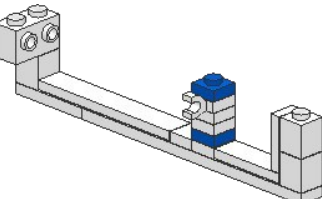

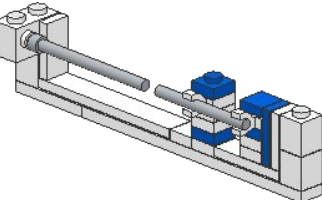

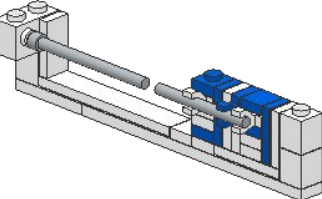

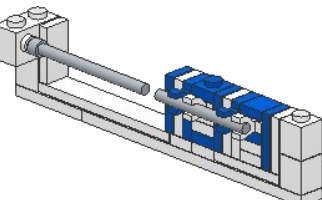

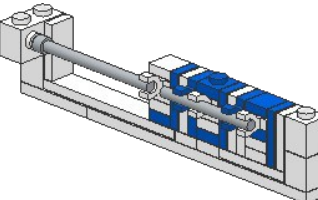

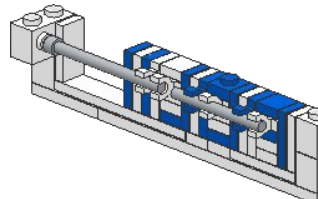

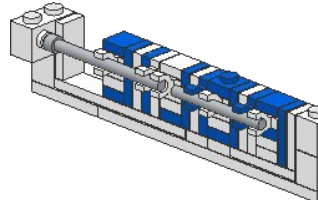

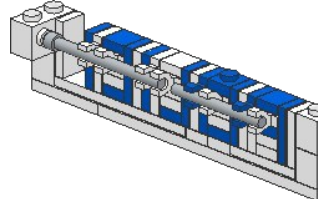
Mosaic Dates on LEGO Modular Sets

These sets (#10197 & 10224) use plates and tiles to create SNOT dates on the buildings.



Clip and Bar Lettering



1. 
2.  
3.  
4.  
5.  
6.  
7.  
8.  
9.  

Example of lettering style similar to that from the fire house and town hall sets.

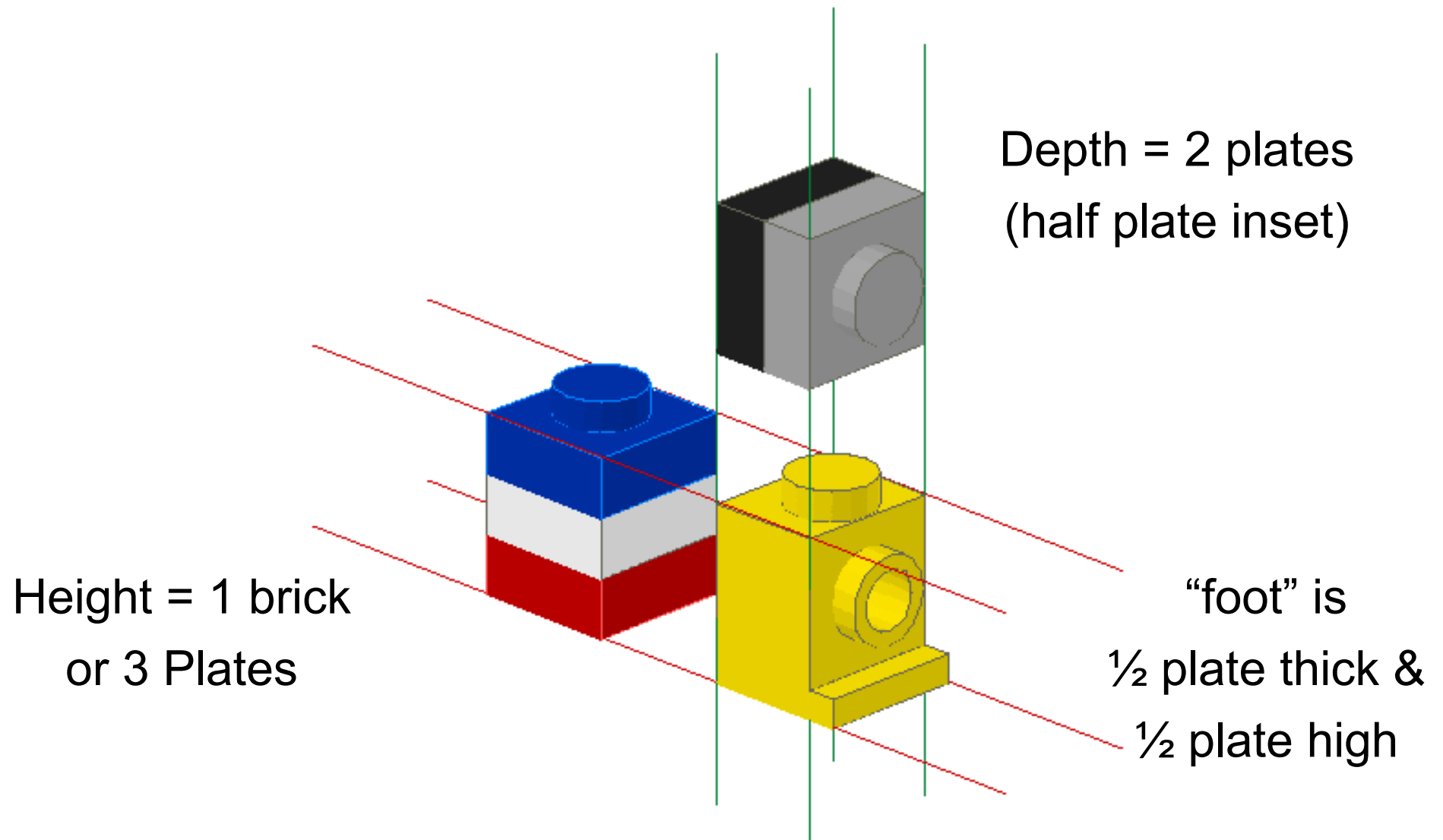
Using this clip and bar technique frees you from worrying about spacing.

Only the middle of the "O" lines up with the studs above and below!

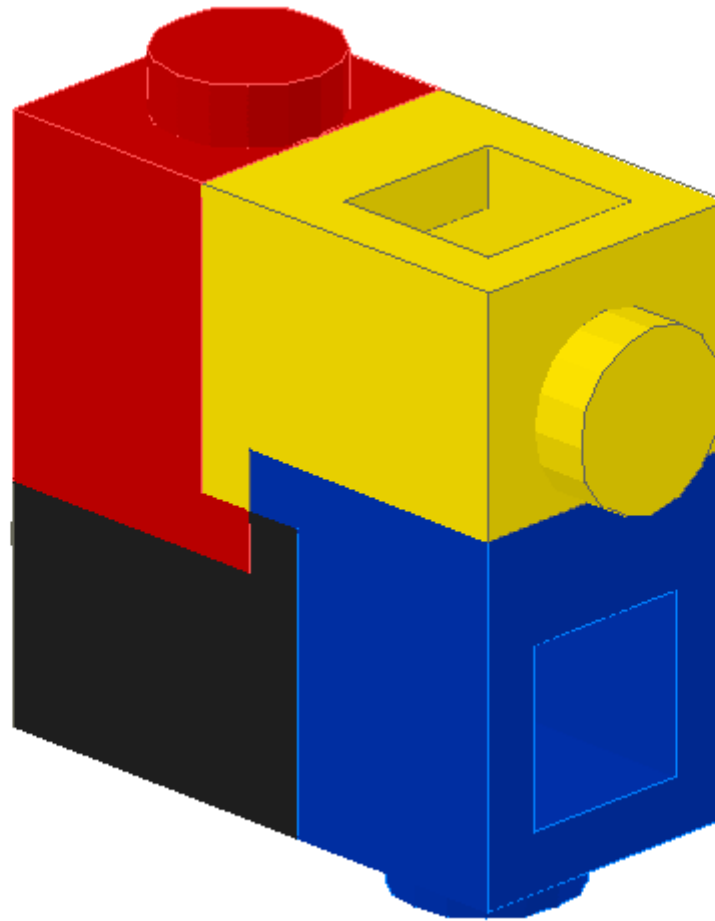


Fun with Headlight Bricks

Headlight Brick Dimensions



Four headlight bricks

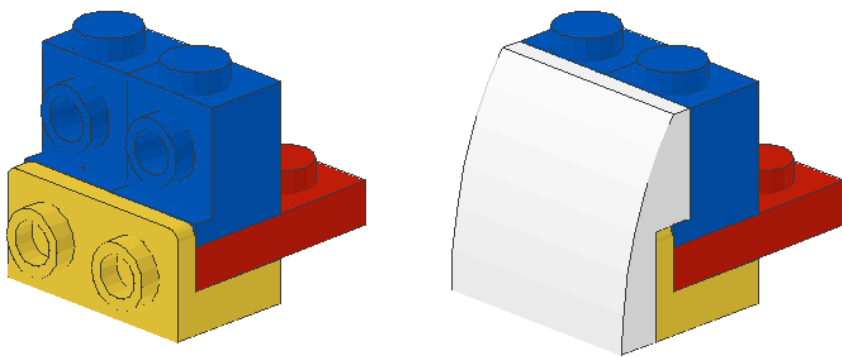


2 plates (red) +
3 plates (yellow) =
5 plates = 2 studs

Result: 5 plates or 2 studs in each of 4 directions.

Combining Brackets & Headlight Bricks

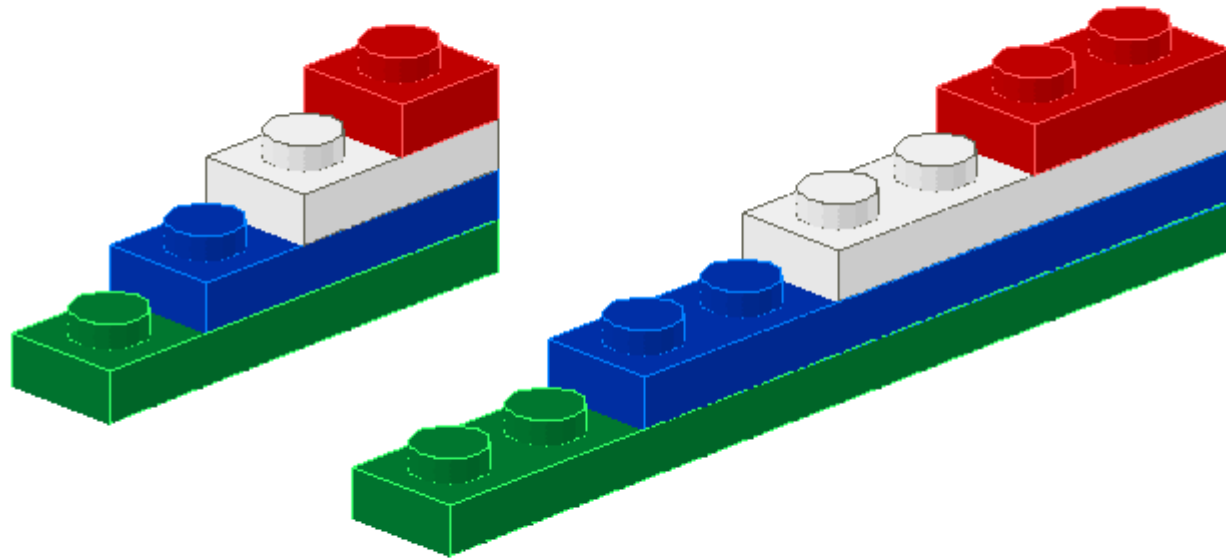
$\frac{1}{2}$ plate offset on headlight bricks +
 $\frac{1}{2}$ plate thickness on bracket =
1 plate thickness, suitable for 2x2
curved slope



*As seen in the LEGO IDEAS Ghostbusters set #21108
(minifig display)*

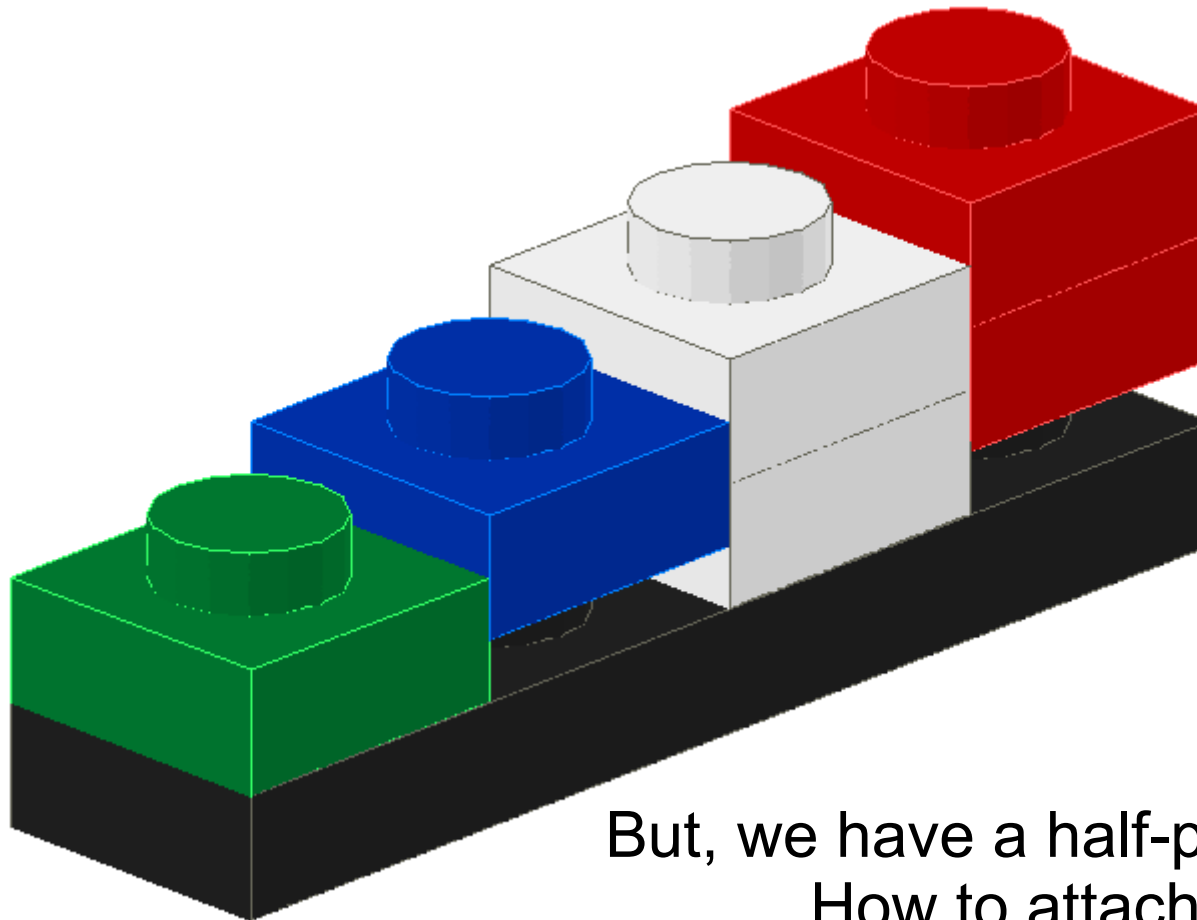
Problem: Gradual Steps

How do you make a gentle slope?
What if these are too steep?



Gradual Steps

For a more gradual slope, we'd like to mount every other one $\frac{1}{2}$ plate higher

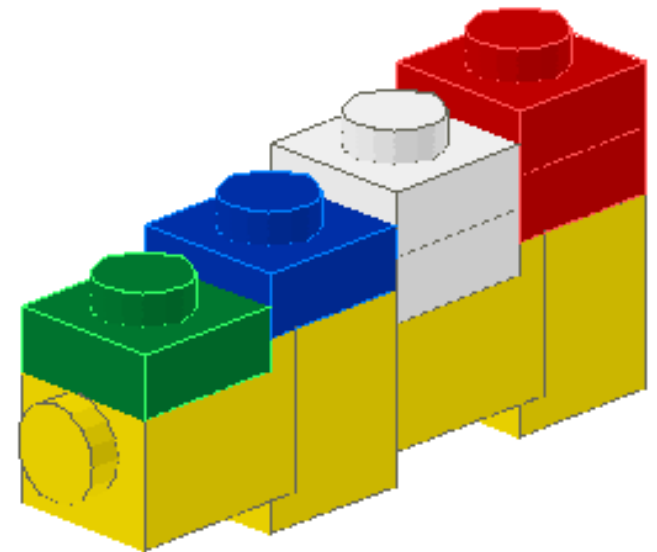
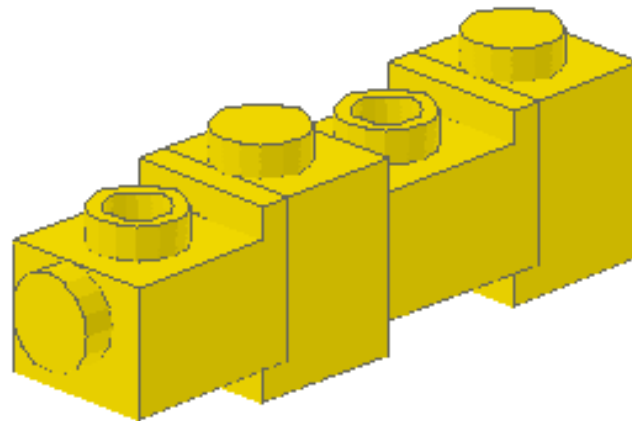


But, we have a half-plate hole to fill!
How to attach these?

Solution: Headlight Bricks

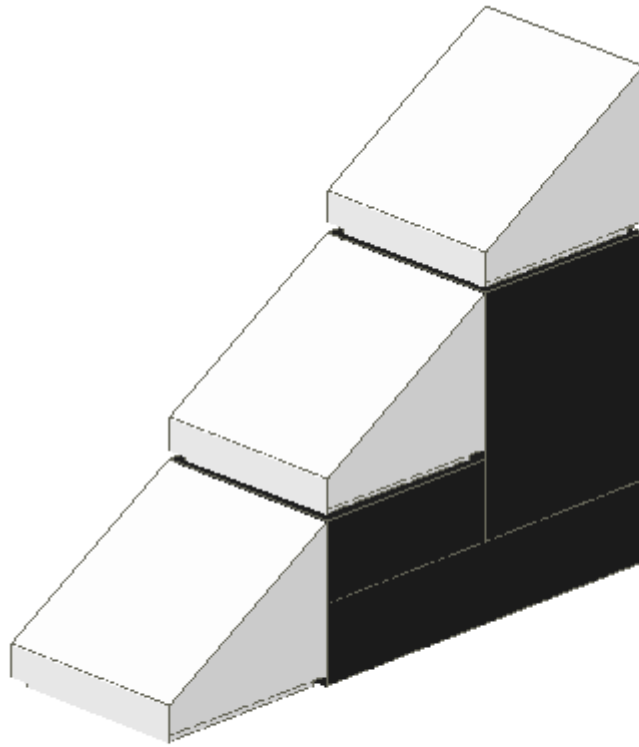
Alternate rotations for headlight bricks to take advantage of $\frac{1}{2}$ plate offset in “foot”

2 plates + $\frac{1}{2}$ plate = 1 stud



Half-plate lift from “foot”

Problem with “cheese slope”: Stairstep effect

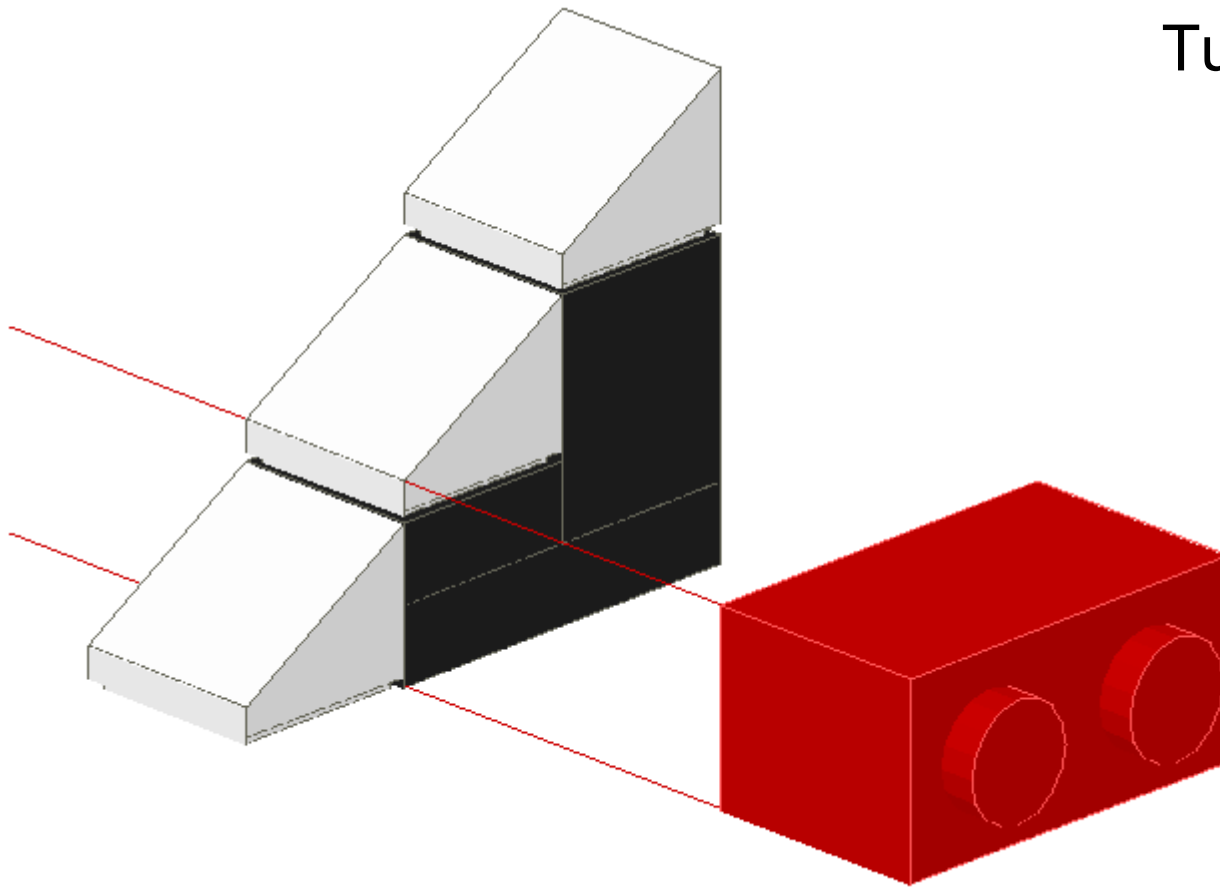


The 1x1 “cheese slope” is a very useful part but doesn't combine well with others of its kind to make a smooth slope.

This notch is needed for it to fit a stud inside, but is ugly.

Problem with “cheese slope”: Stairstep effect

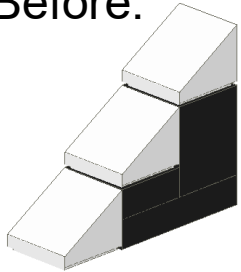
Turns out that “notch”
is $\frac{1}{2}$ plate thick.



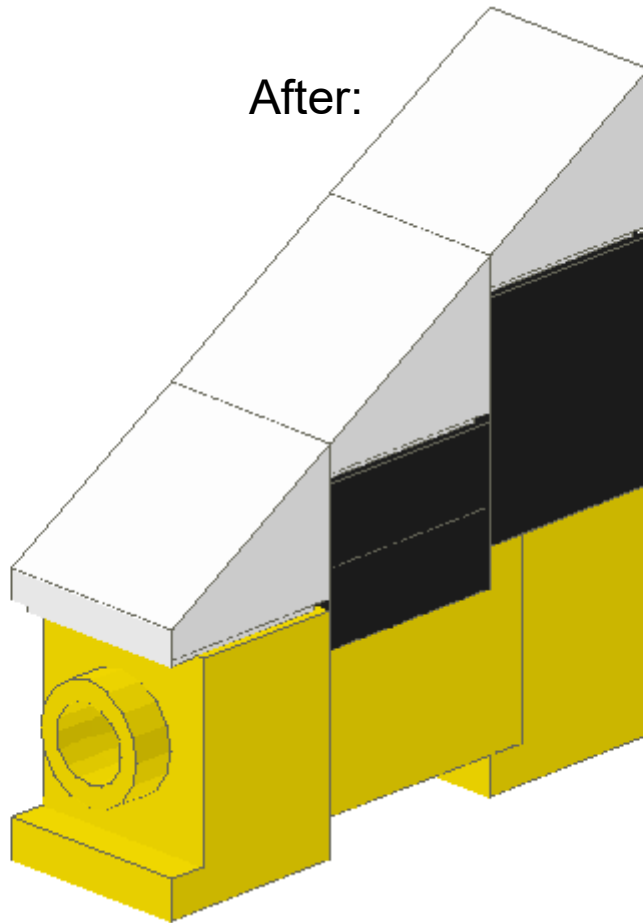
2 plates (height of cheese slope) + $\frac{1}{2}$ plate
= 1 stud

Solving the stairstep effect

Before:



After:

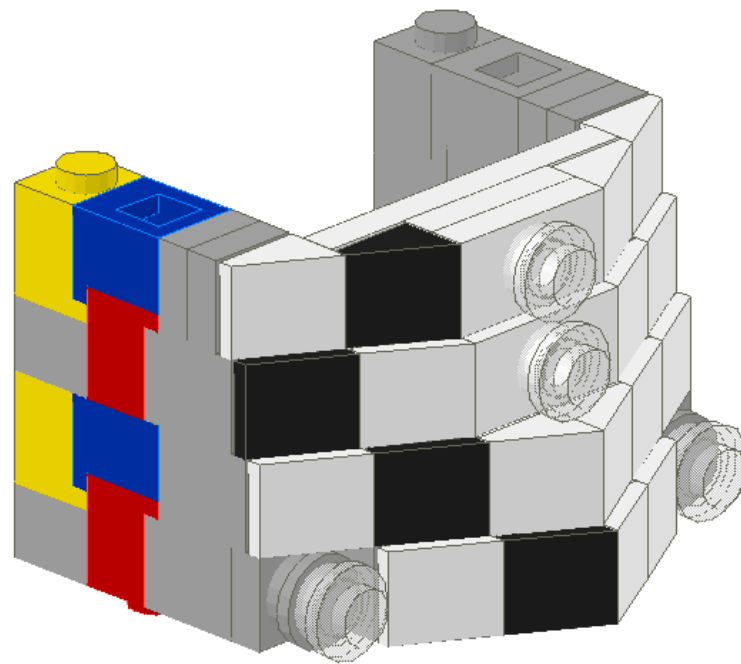


Used in Bram Lambrecht's
“Legoland Spacelines 979”

<http://www.flickr.com/photos/bram/1461137007/>
(used with permission)

Mount the center slope $\frac{1}{2}$ plate lower for a smooth surface!

Useful for trains, too



My F40PH Caltrain locomotive

“Headlight Brick”

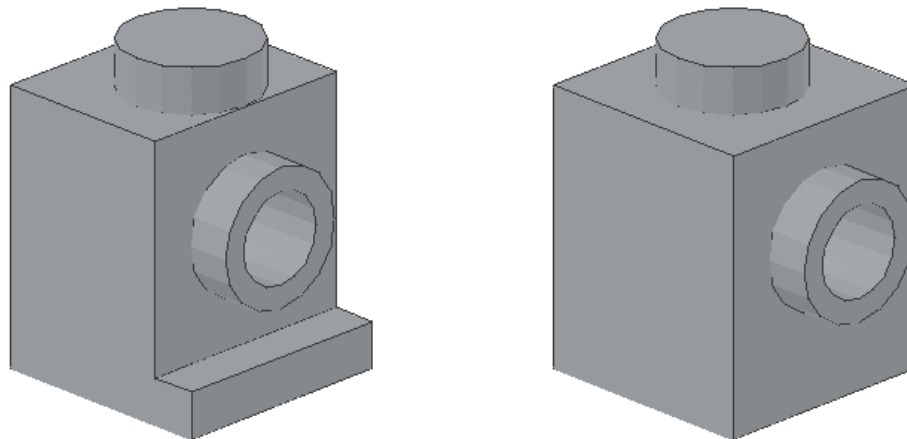
vs.

“Brick 1 x 1 with Stud on 1 Side”

Headlight Brick depth = 2 plates = 16 LDU

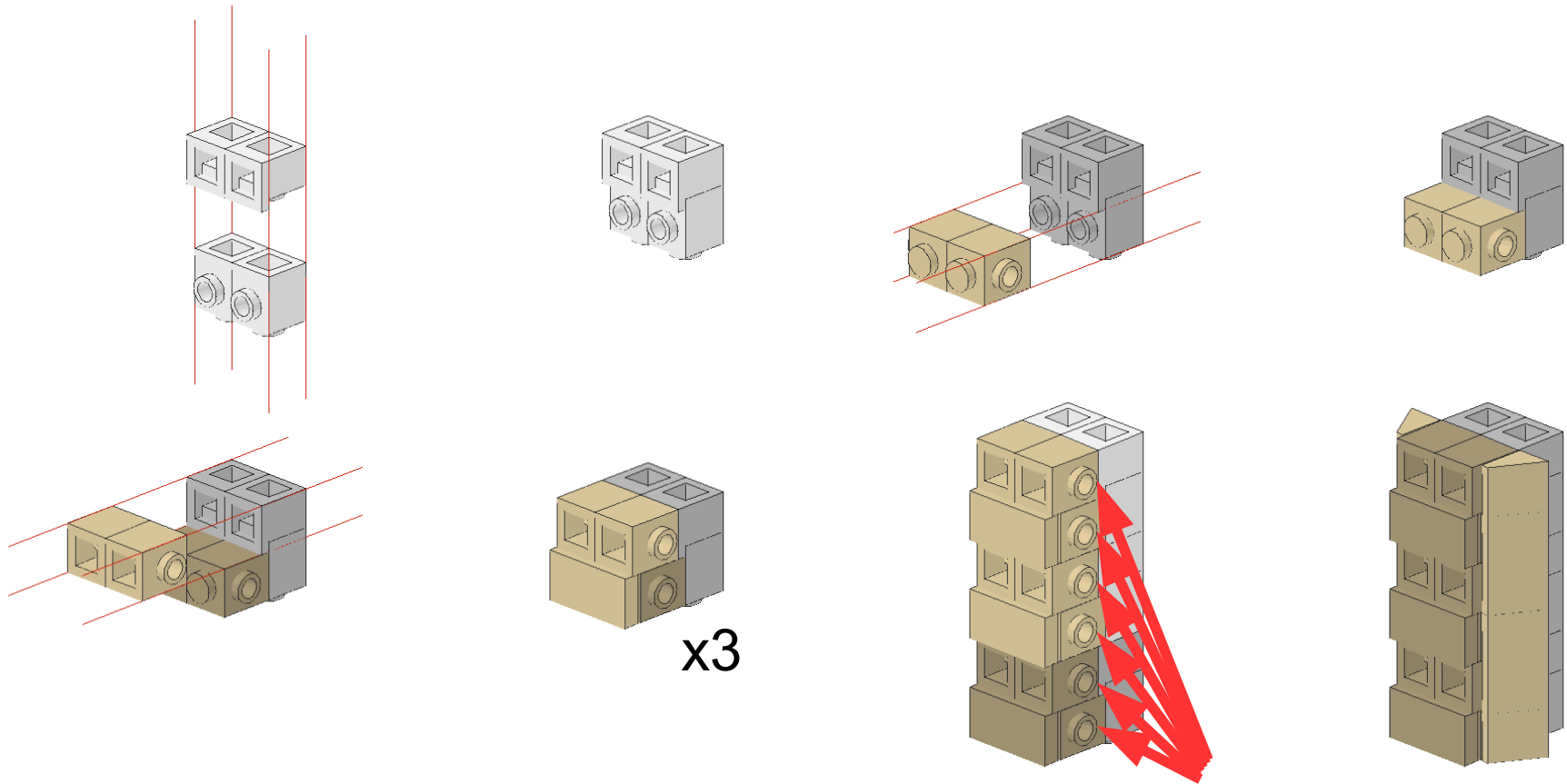
Brick depth = 2 ½ plates = 20 LDU

Combine these to achieve ½ plate differences in depth!



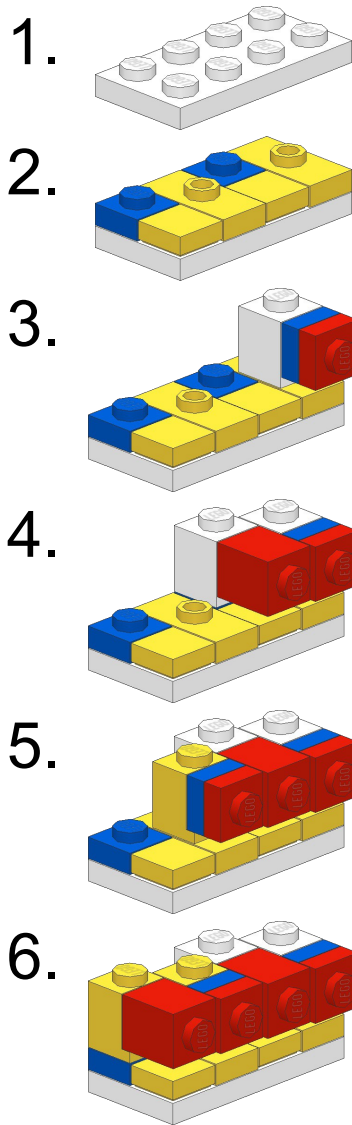
Hospital Bay Window example

Windows (bottoms of bricks) are inset by $\frac{1}{2}$ plate



These studs line up perfectly!

How about QUARTER plate offsets?



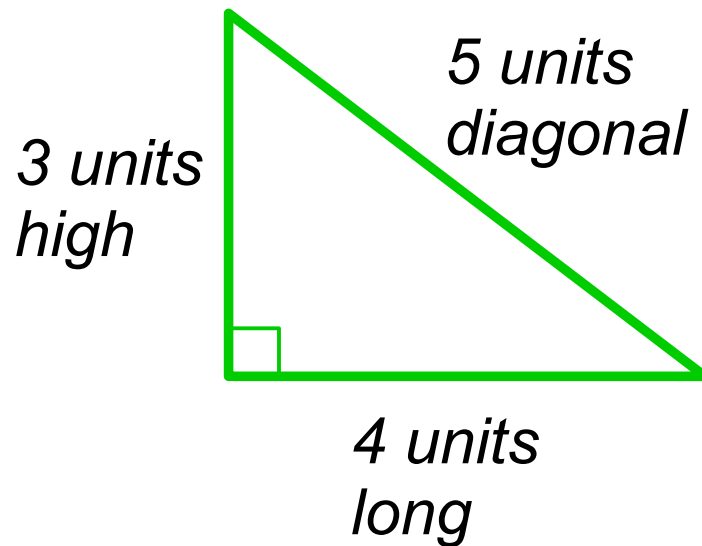
Remember from Vincent Kessels' building that a jumper plate adds a $\frac{1}{4}$ plate offset?

Combine that with the $\frac{1}{2}$ plate difference between the “headlight brick” and the “brick with stud on one side” and get a *very* gradual step.



Triangles

Pythagorean Triples

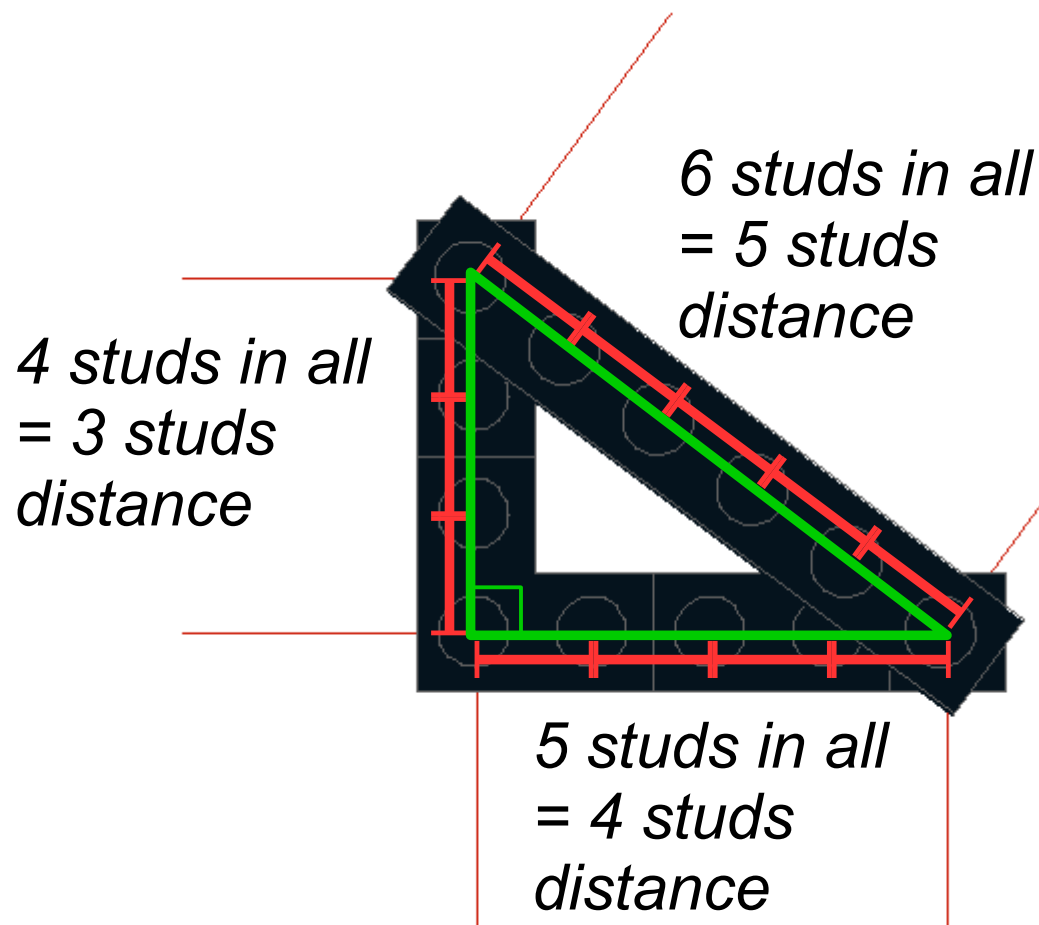


Pythagorean Triples are right triangles where the sides are all integers.

The first Pythagorean Triple is the 3-4-5 triangle. As long as the 3 sides have this ratio it will have a perfect right angle.

Multiples also work: 6-8-10, 9-12-15, etc.

Pythagorean Triples in LEGO



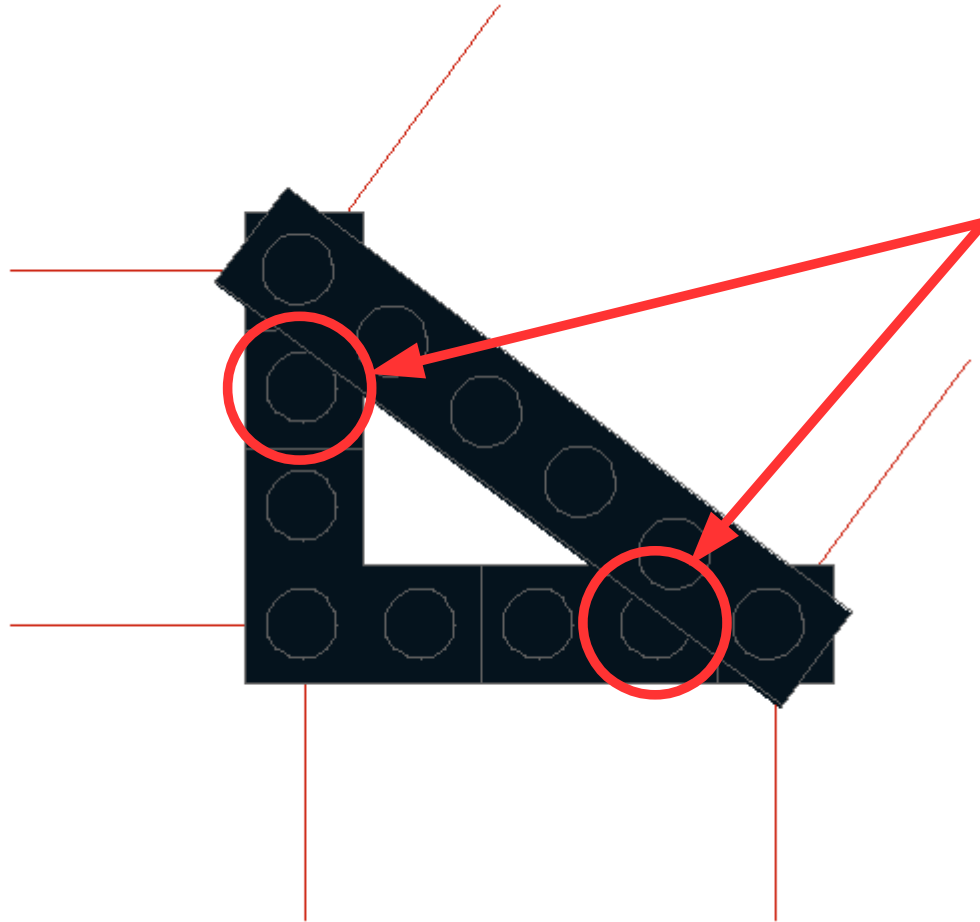
When making a
Pythagorean Triple in
LEGO, add one stud to
each side!

Why? Count *between the*
centers of the studs!

(3, 4, 5) triangle
= (4, 5, 6) studs

(6, 8, 10) triangle
= (7, 9, 11) studs

Pythagorean Triples in LEGO

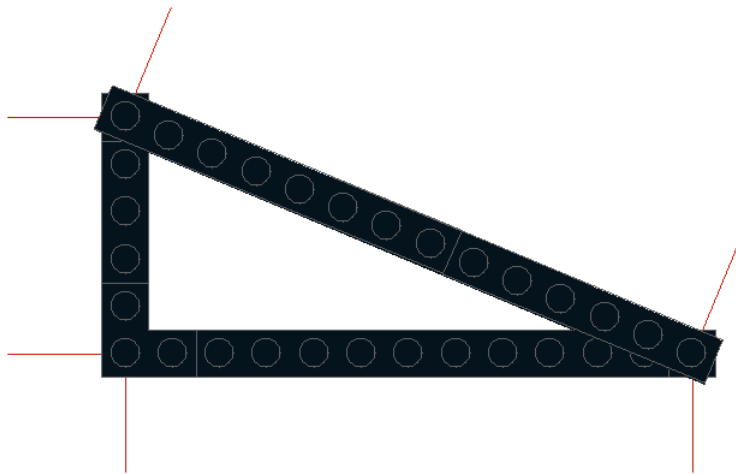


Note: See how the studs are partly blocked by the diagonal.

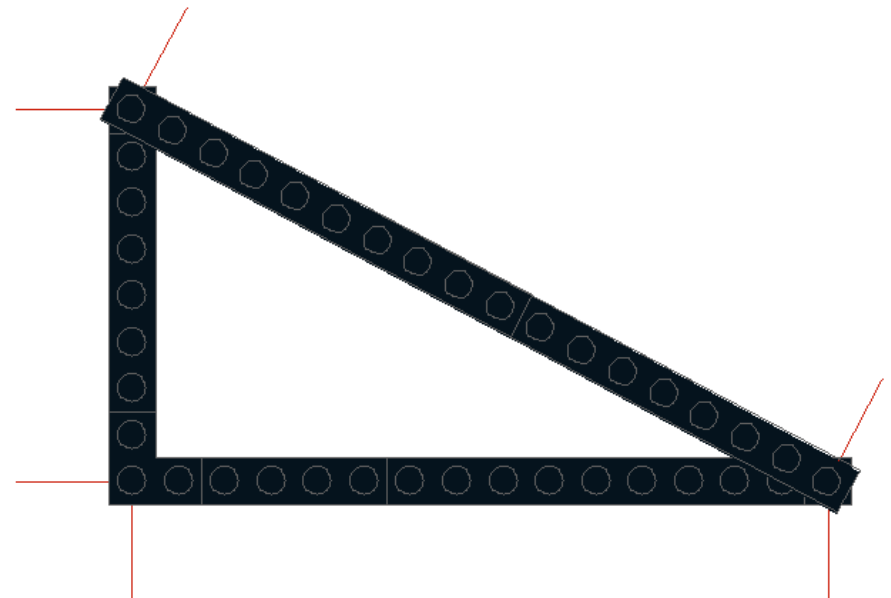
This triangle must be at least three plates thick, due to the spacer plates needed between the diagonal and the horizontal or vertical plates.

More Pythagorean Triples

- There are only 4 triples of diagonal length 25 or less:
(3, 4, 5); (5, 12, 13); (8, 15, 17); (7, 24, 25)
- Any other triangle with integer sides will *not* be a right triangle!
- LEGO Examples:



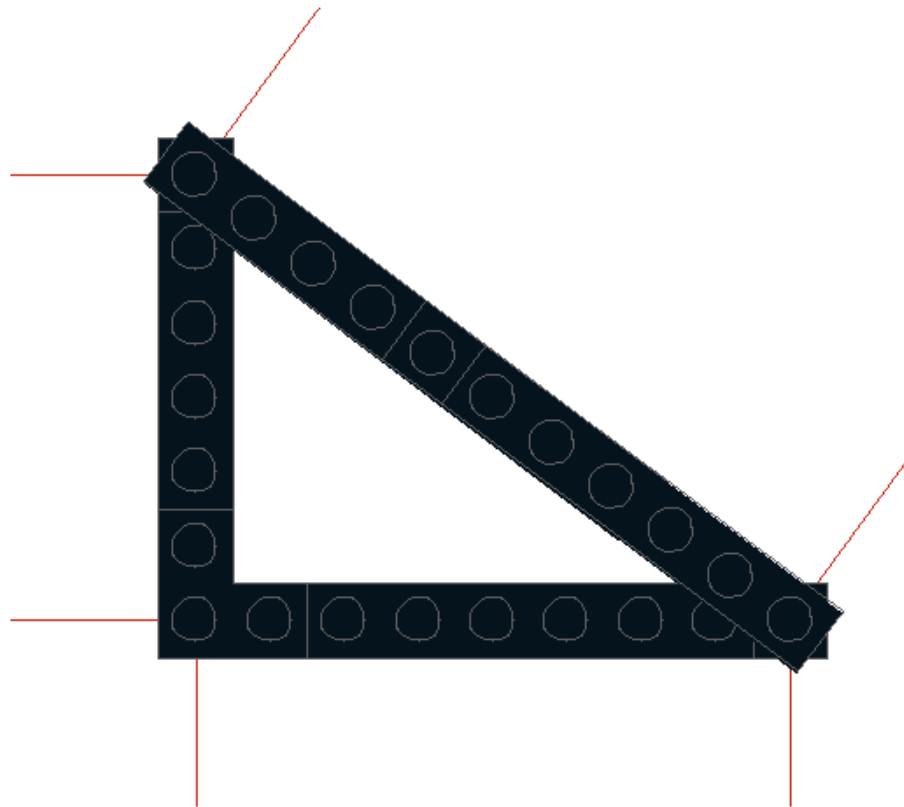
$(5, 12, 13) = (6, 13, 14)$ studs



$(8, 15, 17) = (9, 16, 18)$ studs

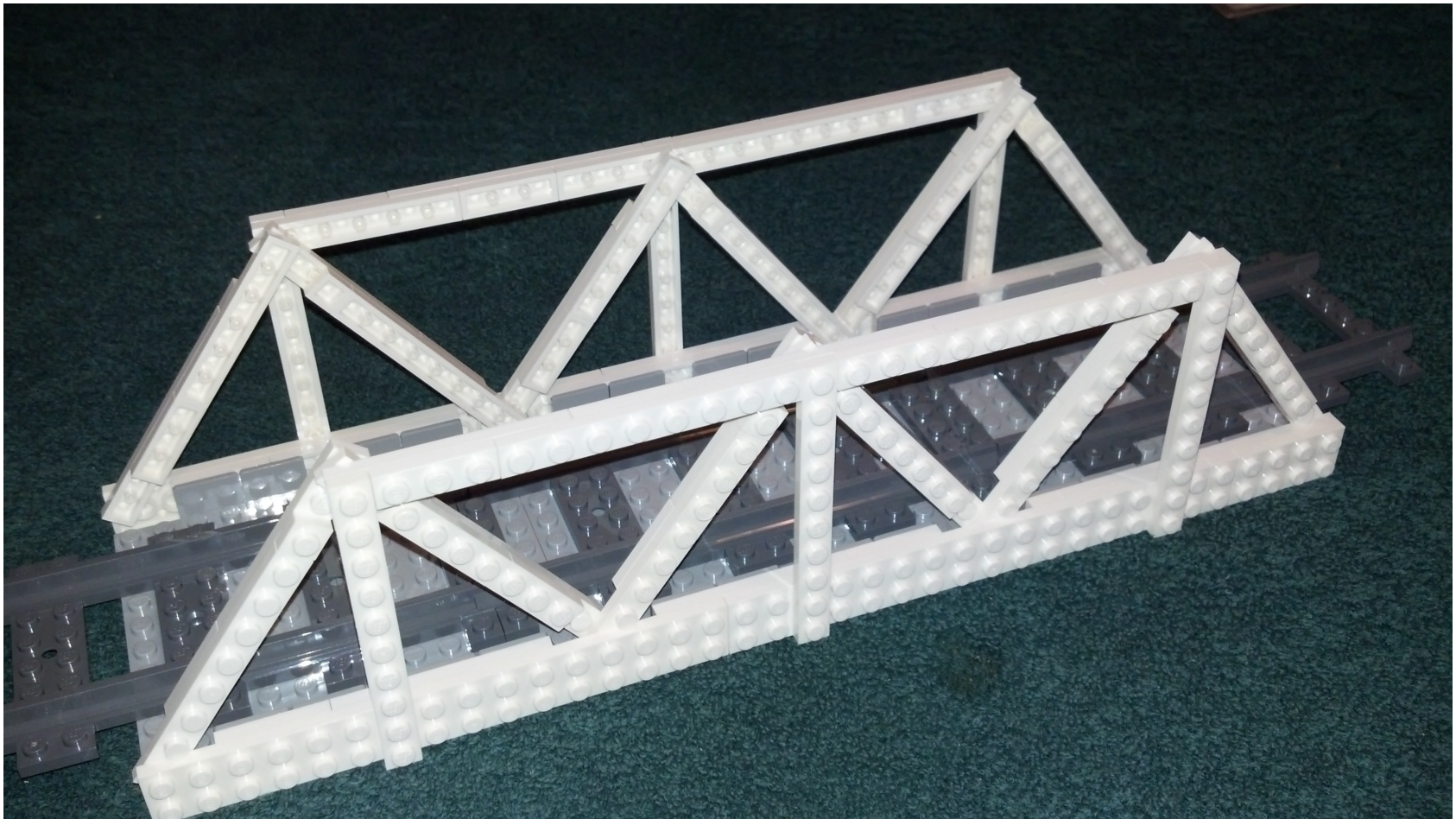
Multiples of Pythagorean Triples

- Unit does not have to be 1 stud! Additional ones can be made by multiplying these values by a scaling factor.
 - Example: $2 \times (3, 4, 5) = (6, 8, 10) = (7, 9, 11)$ studs



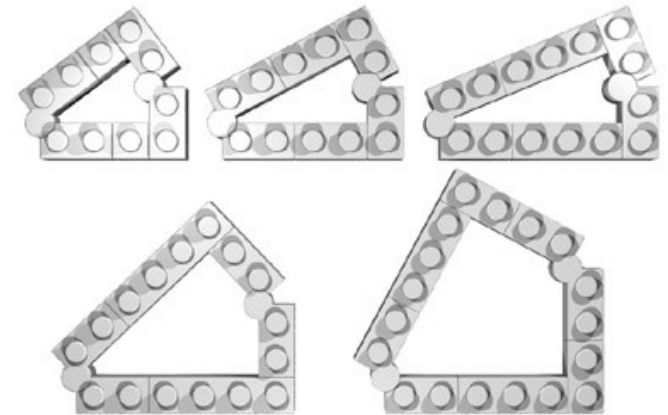
Pythagorean Triple Example: Truss Bridge

Trusses made from (6, 8, 10) Pythagorean triangles



Triangles from Hinges

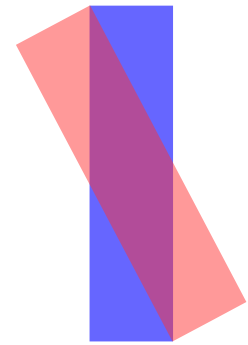
Another way to achieve triangles is to use a hinge element. You can achieve many more possible angles using this technique.



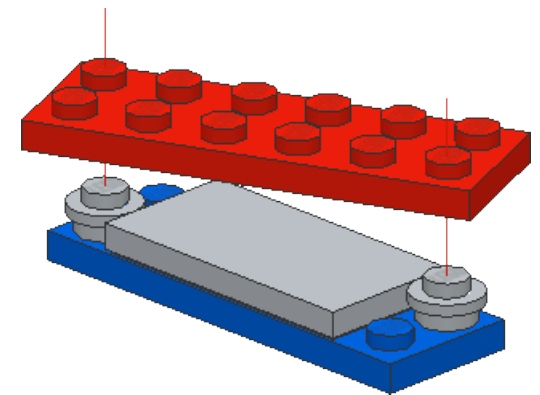
For more information including a list of possible angles, see:
<http://www.l3go.bugge.com/articles/technique/Hypotech1.shtml>

Swap Corners Technique

Two identical rectangles have identical diagonal length. You can therefore place one atop the other, rotated so the corners touch.



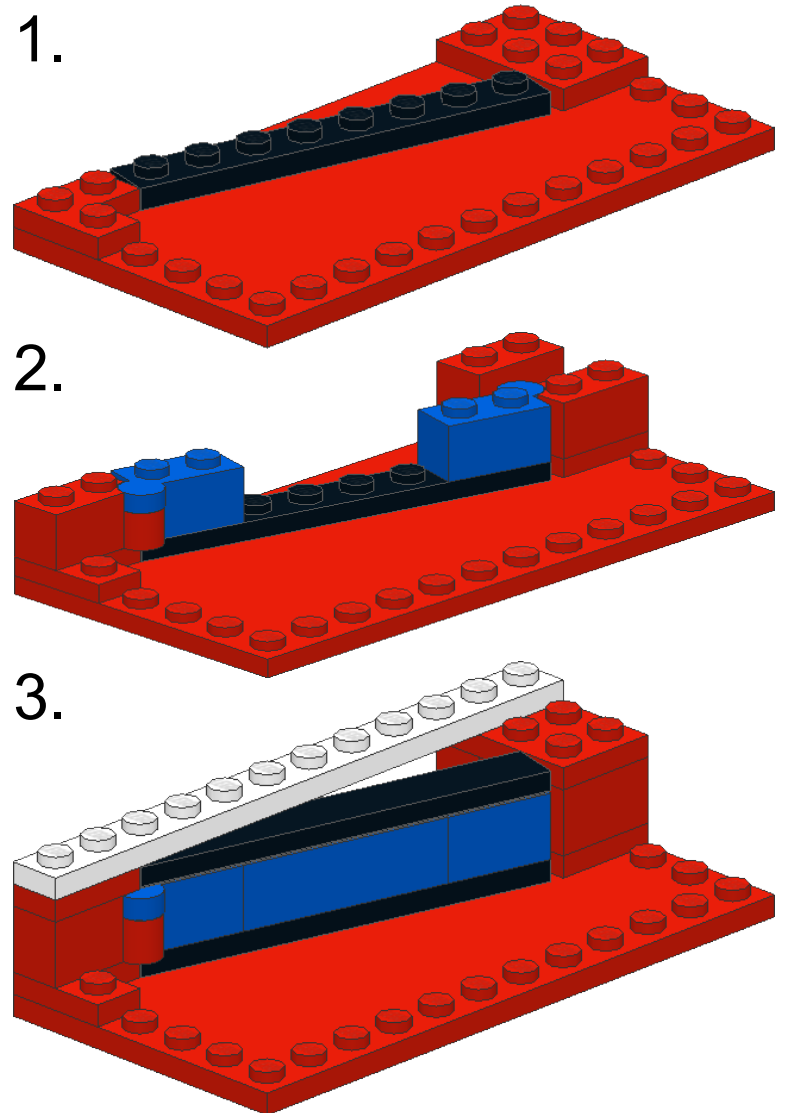
In LEGO, you can do this by connecting the corner studs similarly:



Swap Corners using Hinges

A related technique can be done using hinges, since the rotation point of the hinge is exactly on the corner of the brick.

Example: tapered rear of aircraft fuselage



Additional Resources

- “Offset” page on brickwiki
<http://www.brickwiki.info/wiki/Offset>
- Reinhard Beneke, BrickFest PDX '04
<http://www.brickshelf.com/cgi-bin/gallery.cgi?f=74539>
- MOC Recipes: LEGO Brick Dimensions
<http://mocrecipes.com/2015/09/19/snot-1-lego-brick-dimensions/>
- Sir Bugge's Hypo-Techniques (traingles from hinges):
<http://www.l3go.bugge.com/articles/technique/Hypotech1.shtml>
- The New Elementary, blog about new parts
<http://www.newelementary.com/>
- This and previous versions of this presentation available on my website, www.brickpile.com
<http://www.brickpile.com/tag/brick-geometry/>



Q & A



Thank you

Contact me if you have any further questions...

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