

Three-Dimensional Design

From Two-Dimensional LEGO Mosaic to 3D-Printed Prototype

The mosaic of the previous chapter was two-dimensional. Viewed from a distance, a grid of colored tiles resolved into a crowned crane, but the crane had no depth. It was an image lying on a Baseplate, a picture made of squares. Any sense of a third dimension was an illusion; the same one the collage and the shadowbox created on a flat sheet of paper.

This chapter makes the crane three-dimensional. The flat grid of tiles becomes a figure with height and depth that can be picked up and viewed from every side. The brick replaces the square tile, and the crane is built from units of volume instead of color.

Everything before this step — silhouette, collage, shadowbox, mosaic — worked on a flat surface. Everything after it works in three dimensions and eventually in computer-aided design and 3D printing. Designing the figure and then holding it, first as a printed object and then in brick, is what makes that later work possible. Handling a figure develops an intuitive feel for volume, proportion, and balance that looking at a screen cannot give.

The tiles of the finished mosaic are gathered into named parts — crown, head, neck, wing, body, legs. The mosaic is saved and opened in Sangala Studio. Each part becomes a solid on the same grid it occupies in the mosaic. Depth is assigned part by part, and the flat image rises into a relief. The relief is then mirrored through its own backdrop, giving the figure a front and back. Once printed, it may be a finished figure or a framework over which LEGO bricks are laid. Either becomes the reference for a figure fully built in brick.

The Ishtar Gate

Twenty-six centuries ago, the builders of Babylon also had to make animals from bricks of a fixed size. The Ishtar Gate, built around 575 BC during the reign of Nebuchadnezzar II, is covered in rows of animals against a glazed blue background. Every animal is made of bricks that were molded and fired to standard dimensions. Once a brick was fired, its size was fixed, so the shape of each animal had to be worked out within those sizes before the first row was laid. The aurochs, an ancestor of modern domestic cattle that was sacred to the Babylonian storm god Adad, is one such animal.

The aurochs are now in the Istanbul Archaeology Museums. The same design strategy used to develop the plan for the auroch mosaic will be applied to a mosaic of LEGO tiles.



Figure 5.1. An aurochs from the Ishtar Gate, its form modeled in relief across standard bricks.

The animal is not drawn on the wall; it stands out of it. Each brick that formed part of an animal was molded carrying its own portion of that animal's surface, so the assembled wall pushes the aurochs forward while remaining a wall. The relief is shallow, no deeper than a brick face can be shaped without weakening it, and the whole animal is worked out within that small depth. This is bas relief: a flat image raised into three dimensions, a small amount of depth at a time.

A brick molded with one fragment of an aurochs' shoulder is useless anywhere else in the wall. Every piece had to be shaped for one position and no other. The Babylonians solved this by building the animal once in plain unfired brick, marking the top of each piece with its place in the wall, then taking the whole thing apart to be glazed and fired before it was assembled again. The mosaic and the massing model — the figure reduced to its masses, before any brick is chosen — do the same work. They settle the design on a grid of fixed units while it can still be changed, so that building the figure is a matter of following a plan already made.

The examples in this chapter include a buffalo as well as a crane. The African buffalo is not descended from the aurochs, but it is the same family of animals: a large wild ox, heavy through the shoulders, with horns that sweep outward from a thick plate of bone across the forehead. An animal built from units of uniform size must be depicted from an angle that makes the outline recognizable. The Babylonian craftsmen drew theirs in strict profile. This chapter draws the buffalo the same way.

From Pixel to Building Block

In the mosaic, the unit of construction was the tile: a flat square that marked one cell of a grid with one color. A single tile showed nothing on its own; it became part of a bird only through its position among the tiles around it. The tile itself had almost no thickness, and the whole image lay flat.

A brick is not a point of color but a small block of volume, and a figure is assembled by stacking and interlocking bricks into a form that stands on its own. The mosaic settled which color belonged in each cell of a flat grid. The figure settles how wide the body is, how the extremities meet it, and stable is it?

Learning to see a flat image as a solid form is key to this transition: which parts come forward, which recede, and how the outline of the animal on the Baseplate implies a head, a body, and legs. The same modular logic — designing from repeated units of one size — underlies computer-aided design, first as a visual representation on the computer, and then as a physical prototype in the real world.

Application Workflow

Sangala Mosaic and Sangala Studio were developed to support the methods described in this chapter. Sangala Mosaic allows users to place tiles and group them into identifiable parts. Sangala Studio is used to define each part's level of relief and visualize the figure in three dimensions. It can also modify parts to be compatible with commercial bricks, test whether the model will fit on the 3D printer's build plate, and export files for 3D printing. Every part of the figure is placed by the designer, not generated for them. Because the figure exists as a file, any of those decisions can be easily changed.

Grouping the Parts

Before a depth can be assigned, the designer must identify the parts of the animal. This is done in Sangala Mosaic, by selecting the tiles that make up each part and naming it.

The crowned crane divides into seven parts. Two columns form the legs, rising to carry the body, and the body itself is the largest mass. A column rises from the front of the body as the neck and meets the head, a compact block carrying an eye and a wedge-shaped beak. Across the top of the head a fan of upright pieces forms the golden crown. A wing lies against the body, and a band of grass at the foot gives the figure ground to stand on.

How to divide an animal is settled by recognition rather than by anatomy. Certain features clearly identify different animals — the crane’s crown, an elephant’s trunk, a giraffe’s neck — and each of these has to be its own part. The point is easily tested: shorten the giraffe's neck, take the trunk off the elephant, drop the crane's crown, and each animal stops being that animal. Dividing further adds work without adding recognition. The goal of breaking an animal down into individual parts is not to recreate a photographic likeness. Instead, the goal is to produce a general impression of an animal that can be easily recognized as what it represents.

The designer gathers tiles with Select Area or the Wand and then groups them into a named part. The panel lists every part with the studs it spans, one stud to each tile of the mosaic, and the number of tiles it holds, so a part can be checked against the others for size. A tile belongs to one part at most.

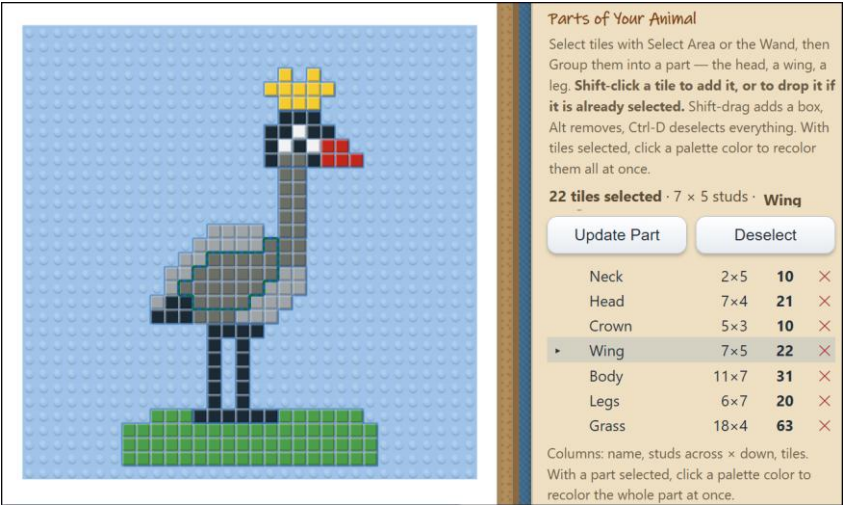


Figure 5.2. The crane's tiles gathered into named parts in Sangala Mosaic.

Tiles not included in a part when exported from Sangala Mosaic arrive in Sangala Studio as individual unnamed parts. The designer must name these parts before giving them depth. Grouping every tile into a named part while the mosaic is still in hand costs less than searching out the remainder afterward.

The photograph the mosaic came from determines how much of the animal can be easily represented in a mosaic. An animal seen in profile generally presents an outline that identifies it clearly, and its parts divide cleanly along its anatomy. For example, a rhinoceros' horns stand clear of the head and can be given their own depth. Photographed head-on, the same horns appear as a shape overlapping the face rather than projecting from it. A head-on subject is better divided by light and shadow than by anatomy. While

this approach is doable, it is generally more difficult to work with head on mosaics in subsequent sections of this chapter.

Carrying the Mosaic into Sangala Studio

The designer saves the mosaic as a .mosaic file and opens it in Sangala Studio with the Open button. Each named part appears as a separate solid standing in the place of the tiles it occupied in the mosaic, in the color it had there. The two applications use the same measurement: a mosaic tile is 8 mm square, and LEGO studs are spaced 8 mm apart. One tile is therefore one stud, so a neck two tiles wide in the mosaic is a neck two studs wide in brick.

Because one tile is one stud, the size of a design follows from the number of studs it spans. A full Baseplate of 32 by 32 studs is 256 mm square. Sangala Studio provides a workspace of exactly that size, called “LEGO baseplate 32 x 32 studs”. It is under Settings, then Page size (material). Select it for any design meant for brick or for 3D printing.

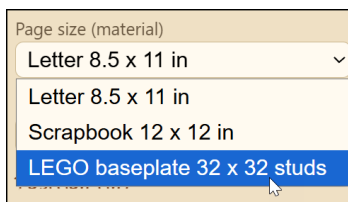


Figure 5.3. The workspace options, with the LEGO baseplate selected.

The bed of a Bambu Lab A1 mini measures 22 by 22 studs, so a figure occupying a full Baseplate cannot be printed in one piece. The design steps are unaffected; the bed's size governs only how the finished figure is split for printing.

Height is where brick and tile differ. A brick stands 9.6 mm, making it slightly taller than it is wide, and a plate is a third of a brick at 3.2 mm. Sangala Studio counts height in plates rather than millimeters, so a plate has a height of 1 and a brick has a height of 3. Millimeters are the unit of the printer; plates are the unit of the builder.

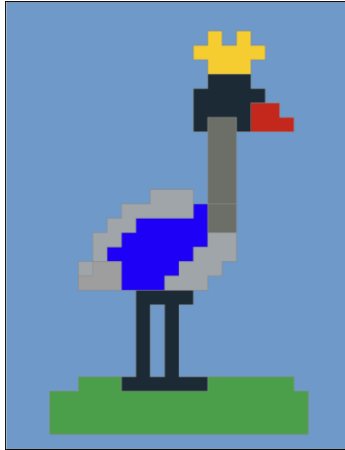


Figure 5.4. The mosaic opened in Sangala Studio, each named part now a solid.

Giving the Parts Depth

A part with no depth is an outline with nothing to print. Giving different parts different depths turns the flat image into a relief.

The work is done a plane at a time. A plane is a group of parts that stand at the same distance from the backdrop — the flat plane the mosaic lay in, from which every depth is measured — and every part in a plane shares one setting: the crane's grass is set once, and the parts standing in front of it are set together on their own plane. Each plane carries a *Depth*, which is how thick its parts are, and a *Base*, which is how far forward they start. The *Base* produces the relief: the wing standing one plate above the body, the head one plate above of the neck.

Base means two different things in Sangala Studio. In a relief it is how far forward a part stands from the backdrop. After the figure is mirrored later in this chapter, the same field becomes the distance of a part from the midline.

How much depth a figure needs is judged by building the alternatives and looking at them. A total spread of about four plates from the farthest part to the nearest gives a shallow relief, and is the practical minimum. About seven plates gives a deep relief, and is the reference case for an animal seen in profile. Beyond about eleven plates a figure begins to come apart. A single plate of separation is enough to see, because the eye sees the shadow at the edge of a step rather than the height of the step itself.

Depth also settles which part stands nearer the viewer than its neighbor, something a flat mosaic cannot express. On the crane the wing stands nearer than the body. This is done

by bringing the wing's own tiles further forward, not by laying new pieces over the body. No part can hide another, since each tile belongs to one part only; what the reader sees at each shared edge is a step and the shadow it casts.

What results is a massing model. It gives the shape, size, and proportions of the figure — how wide the body is, how long the neck, which parts come further forward — but it does not say which bricks to use. That choice is the design work, and it is left to the builder.

Wherever the model steps from one depth to the next, the designer can choose a shaped piece — a slope or a wedge, cut at an angle rather than square — instead of leaving the step square. The steps in the relief mark where such a piece could go, but it is up to the designer to determine whether they should be added and what exact shapes they should be.

What is designed as one animal can print as separate solids. Every tile belongs to exactly one part, so no two parts ever overlap when viewed from above. Two parts that meet are joined in three dimensions only where their sides touch. This means that a raised part must share a face with the parts around it. Its *Base* must be at least one plate below the top of the adjacent. A part raised to exactly the top of its neighbour touches along a single edge and is not joined to it. If raised higher, it is not touching at all. The application cannot detect whether or not parts are overlapping, so it is important to follow the rule rather than relying on visual inspection of the model.

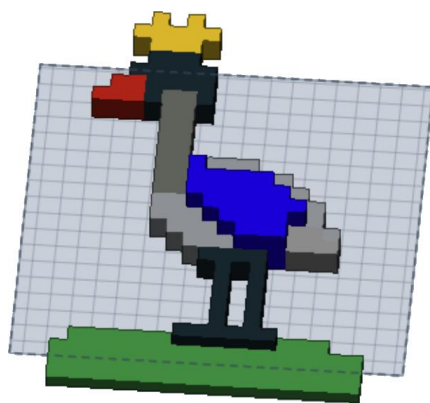


Figure 5.5. The crane in relief, the wing extruded from the body.

Mirroring for Symmetry

A relief has a front and no back. Mirroring gives it one. A plane set to mirror is reflected through the backdrop, so that whatever stands in front of it is matched behind, and the figure becomes solid on both sides.

Mirroring is set one plane at a time. This makes it possible to mirror only the parts that require a reflected opposite side. The mirror control beside each plane's name has three states: Front half only, Both halves, and Back half only.

Mirroring makes two assumptions. It assumes the animal to be symmetric about the plane the mosaic lies in, which a crane seen in profile nearly is. It also takes each part to be as deep behind that plane as the relief made it in front, which is a choice made for appearance and not a measurement of the bird.

After mirroring, *Base* takes its second meaning: the distance of a part from the figure's midline. A part with *Base* 0 starts at the midline, so it and its reflection meet there and join into one solid. A part given a *Base* above 0 is separated from its reflection by twice the *Base* value, which is how the paired parts are kept apart. On a crane in profile nearly all parts meet at the midline when reflected around it. This makes it a simpler subject than animals that have parts that are raised in relief above the midline (e.g., the horns of a buffalo)

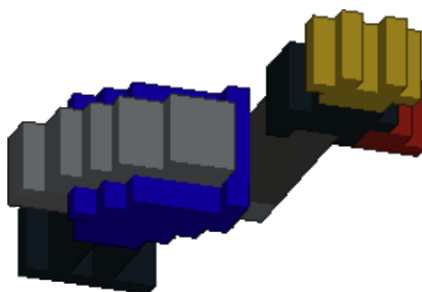


Figure 5.6. The same crane mirrored, and now a solid figure.

The Buffalo

The crane is finished, transformed from a grid of tiles to a figure with a front and a back. The buffalo follows the same path, but two of its problems are harder. A crane in profile is unmistakable from its outline alone; a buffalo must be posed and cropped with more care before its outline identifies it. Additionally, its horns are a pair that must be pulled apart from each other rather than meeting at the midline as the crane's paired parts do.

The pose is the first decision. A buffalo in profile shows its length, its height, and the line of its back, and the far side can be assumed to match the near one. Head-on, the length of the body is hidden behind the head, and there is no way to judge the animal's proportions from what is visible. The head-on outline is also shared: a broad head, heavy shoulders, and outward sweeping horns describe an American bison or a musk ox as readily as an African buffalo. In profile the three can be identified by more individual characteristics.

— the bison by its larger shoulder hump, the musk ox by its long coat, the buffalo straighter back that sits above its head.



Figure 5.7. A crowned crane drawn in profile (left) and a buffalo drawn head-on (right).

Two or three features carry the silhouette. A buffalo is recognized by its curved horns and by a head that sits just below its back. Until both are present the drawing looks like a barrel with a box on one end.



Figure 5.8. The buffalo in profile.

Only the near pair of legs is drawn. Four legs drawn side by side would all be given the same depth and would come out as four slabs standing in one plane. Instead the designer gives the near legs a *Base* that lifts them off the mirror plane, so that mirroring produces the far pair, separated from the near one. The horns are handled the same way: the designer draws one horn, gives it a *Base*, and mirrors it into a pair.

Once the paired parts have been positioned, any changes to the body depth require changes to the paired parts' *Base*. If body depth is increased but the part *Base* stays the same, the body will stand too far in relief above the paired parts. If the body depth is decreased, the paired parts will float unattached above it.

Grouped, the buffalo comes to seven parts — horns, head, body, legs, tail, a bird, and the grass it stands in — close to the crane’s count and divided on the same principle. The panel lists each with the studs it spans, so the parts can be compared by size before any of them is given depth.

Horns	9×3	13
Head	8×8	54
Body	20×11	181
Legs	12×8	72
Tail	2×9	11
Bird	8×6	23
Grass	30×4	96

Figure 5.9. Every tile grouped into a named part, with the studs each part spans.

The *Depth* and *Base* for the buffalo parts are listed below, measured in plates.

Table 5.1. The depth and <i>Base</i> values that produce the buffalo.			
<i>Part</i>	<i>Depth (plates)</i>	<i>Base (plates)</i>	<i>Reason for the Depth and Base Settings</i>
Body	5	0	The body, head, and tail all rest on the Baseplate and therefore have a <i>Base</i> of “0”. The body is thicker than the head and tail and therefore has a <i>Depth</i> of 5.
Head	4	0	
Tail & Bird	3	0	
Legs	3	3	The left and right legs (front and back) are separated.
Horns	4	4	The horns are separated (on either side of the head).

These settings produce a figure that is a single connected solid; no parts floats free.

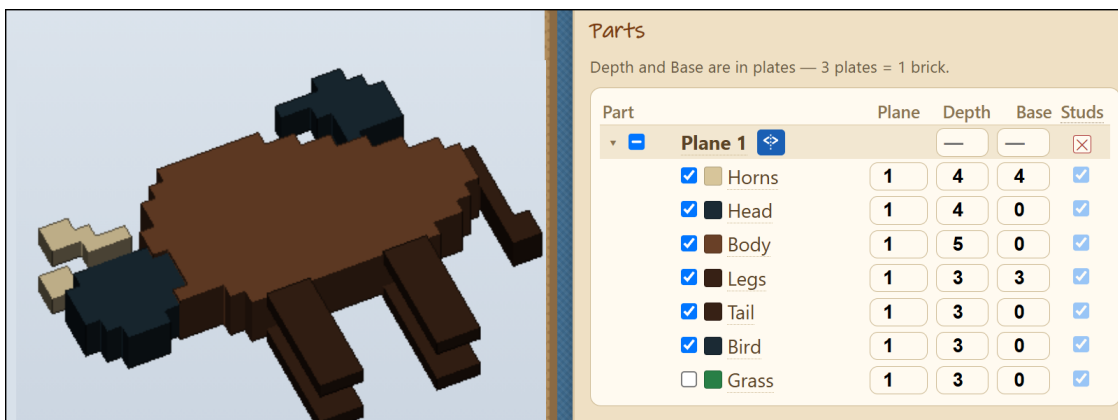


Figure 5.10. The mirrored figure, with the depth and *Base* values that produced it.

Printing the Figure

Sangala Studio exports whatever the three-dimensional view is showing. A part or a plane hidden in the view will not be exported as part of the file. This makes printing figures that are larger than the bed possible.

A design that fills a baseplate is 256 mm across, and the bed of a Bambu Lab A1 mini is 180 mm square, so large figures must be printed in more than one batch. On the crane, everything but the legs fits. Hiding the legs and exporting the rest of the figure, and then showing and exporting only the legs produces two pieces of the bird that can be printed separately and then assembled. Engineering is largely a matter of working within limits. The printer's bed is one of them, and deciding early which parts go on it together is part of designing the figure.

A figure with a front and a back has overhangs on both sides, and printing it whole requires supports printed underneath them. Each half laid flat on its cut face needs no supports. Set the mirror control to the front half and write the file, then to the back half and write it again. The halves are joined afterwards along the flat face where they met. This splitting is in addition to any splitting the bed requires: a crane whose legs will not fit alongside the body becomes four files rather than two.

Two commands write two different files. *Export STL* writes the file the printer reads. *The Save menu has two options: “Save as SVG” and “Save project”; the “Save project” option saves a file with a “.model” extension that can be reopened to reload the project. The STL prints the object; the .model keeps the design.* Parts that are hidden with an STL is exported will still be preserved in the file when it is saved.

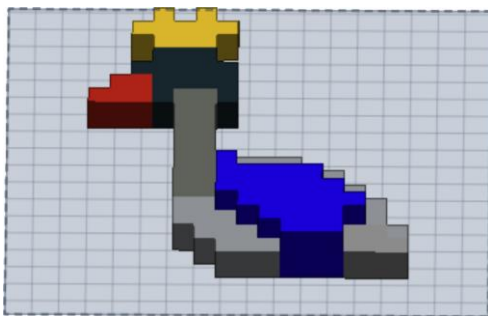


Figure 5.11. The legs hidden, so that what remains is what the exported file will hold.

A Printed Figure, or a Framework for Brick

The printed figure can be finished in two ways, and the choice has to be made before the file is written.

It may be printed unchanged, without studs. The result is a solid figure with smooth surfaces, and its shape is limited only by what the printer can produce. Studs make a massing model recognizable as LEGO on the screen, but they do nothing on a printed object that will receive no bricks. They can be turned off for a part, for a plane, or for the whole figure. The plane's Studs box overrides rather than rewrites, so each part's own setting returns when the override is cleared.

Or it may be printed as a framework to be skinned. Studs are printed on the surfaces where LEGO bricks will be pressed on, so the printed form carries the mass and the strength while the bricks supply the surface. Building from brick alone means working with a finite set of shapes: a beak becomes a slope stopping short of a point, leaving a small upright wall, because no wedge in the supply comes to one. A printed part is not restricted to those shapes. Where a shape exists in brick, the print stays underneath and the brick shows; where it does not, the print is left bare and shows the shape the designer intended.



Figure 5.12. A printed framework with a skin of LEGO bricks applied over it.

Building the Figure in Brick

A printed figure is the reference for building the same animal entirely from brick. It can be measured with a ruler and turned over in the hand, which a model on a screen cannot.

The builder approximates each part from the bricks available, rebuilding the rounded body of the printed figure from rectangular bricks and making its slender neck thick enough to stand. The finished figure therefore differs from the printed one, and part of that difference comes from the colors and shapes available, and how many of each, rather than from the design.

A figure that looks right but topples over is not finished. A wide, low base, a low center of gravity, and strong connection between bricks improve model stability. The thinnest features of a model likely need reinforcing. For example, a longer, thin neck on the crane might look more anatomically accurate but be unstable and break when handled.

A build can be tested. Tilting the baseplate a few degrees, or turning the figure over, finds the parts that were not connected strongly enough.

The builder builds the body as a plain rectangular core, resting shaped pieces on it and mounting them at its sides. The figure should stand without them; the core carries the structure, and rectangular bricks provide support. Shaped pieces can add to it — one bridging a seam in the bricks beneath ties them together — but nothing depends on them.

Once the brick figure is built, the builder compares it to the mosaic and the printed figure. Is the neck too short or the body too narrow? Each comparison points to a specific adjustment, and because bricks come apart easily, the cycle can be run many times in a session.



Figure 5.13. A completed LEGO crane figure, built from the *Base* upward.

Those ready for more can add moving parts — a jaw that opens, wings that lift on a hinge — using LEGO’s own connectors. These are not required, but they extend the figure from a static sculpture toward the animated, mechanical work that follows.

Because the bricks come apart as easily as they go together, rapid changes are possible.

The Value of a Physical Prototype

A printed figure may be the finished work, and the animal does not have to be built in brick. A print shows whether the proportions hold at full size, and it can be balanced in the hand. What it cannot show is what must change when the form is rebuilt from a finite set of pieces. Only a build in brick shows that, and LEGO-style bricks shows it fast and cheaply.

Physical Prototyping

A prototype is an early, approximate version of a design, made to test whether it works before committing to a final form. A LEGO figure built in 20 minutes can reveal that a neck is too thin or a body too heavy — discoveries that would be expensive to make after hours of CAD modeling or a failed 3D print.

Professional engineers and designers prototype constantly, in cardboard, foam, clay, and bricks, because a rough physical model teaches what a drawing cannot. The LEGO figure is a prototype in this sense. It is not the finished crane; it is what the finished crane is designed from.

The bricks also provide a measuring system. Because a stud is always 8 mm from the next and a brick is always 9.6 mm tall, a figure designed this way can be described to someone else exactly. For example, a body six studs wide ten studs long is an instruction another builder can follow.

Examples of LEGO Figures

The figures below were each built in brick from a two-dimensional mosaic, and each ran into the same gap between the form that had been pictured and what the bricks allowed.

Julia Skinner and Claire Mills built a hippopotamus, choosing to emphasize the animal's most recognizable feature — its wide, heavy jaw — and giving it a mouth that opens on a hinge. The round body that read easily as a flat side-view mosaic proved harder to state

in three dimensions, where its bulk had to be built up from rectangular bricks without losing the hippo's low, heavy stance.

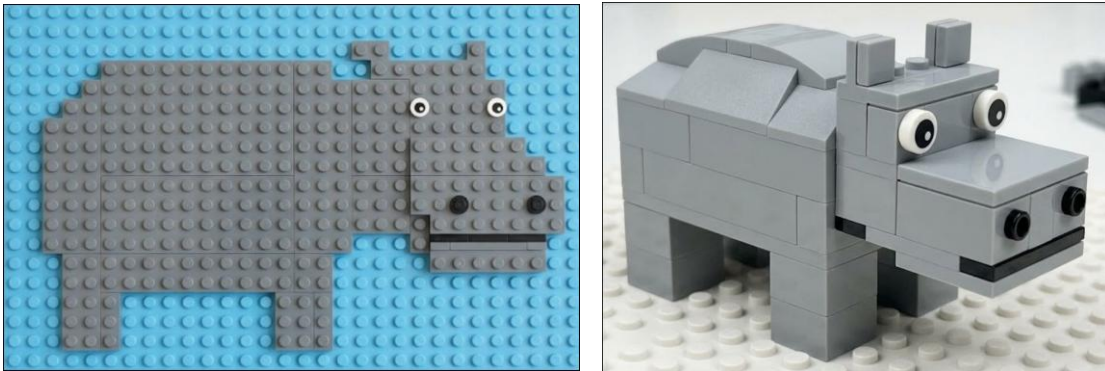


Figure 5.14. A two-dimensional hippo (left) transformed into a three-dimensional figure (right).
(Julia Skinner & Claire Mills)

Annalise Padilla and Kennedy Gordon chose the Great Blue Turaco. They built its wings on movable joints so they could be raised and lowered. They also gave particular attention to the long tail and head feathers that distinguish the bird.



Figure 5.15. A Great Blue Turaco with wings on movable joints. (Annalise Padilla & Kennedy Gordon)

Billy Ganbold carried his elephant forward from its earlier collage and mosaic, keeping the color palette but rebuilding the form. The trunk and tusks — the features that make the figure unmistakably an elephant — were the hardest to attach securely.

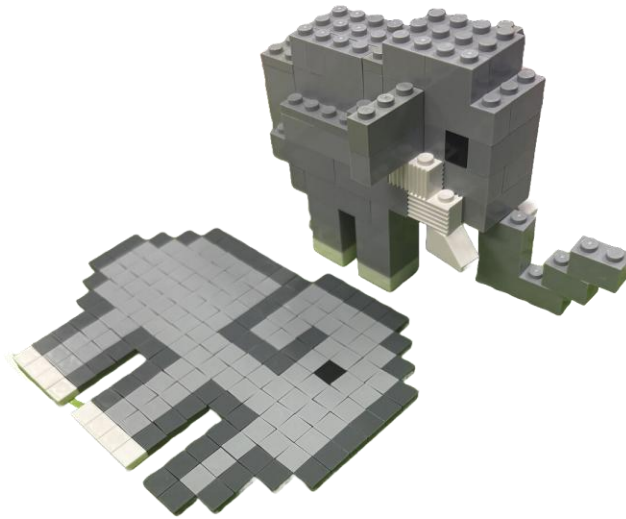


Figure 5.16. A three-dimensional LEGO elephant *Based on a two-dimensional mosaic.* (Billy Ganbold)

Accounts of the process of translating two-dimensional LEGO mosaics into three-dimensional LEGO figures are gathered in the *Educational CAD Model Library* forum.

Looking Ahead

The crowned crane now stands as a three-dimensional object: divided into parts, given depth part by part, mirrored to give it a back, printed in halves, and finished either as it came off the printer or under a skin of brick.

Reaching that point also required keeping the design in a file that reopens exactly as it was left. Chapter 6 takes that printed prototype and translates it into a kit built entirely from LEGO bricks.

The crane has now been a photograph, a silhouette, a collage, a shadowbox, a mosaic, a relief, and a solid figure. Each step has put a new question to the same subject. This chapter's question was what the shape becomes when it must stand up in space.