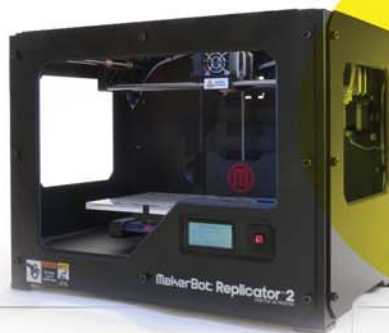


3D PRINTER BUYER'S GUIDE

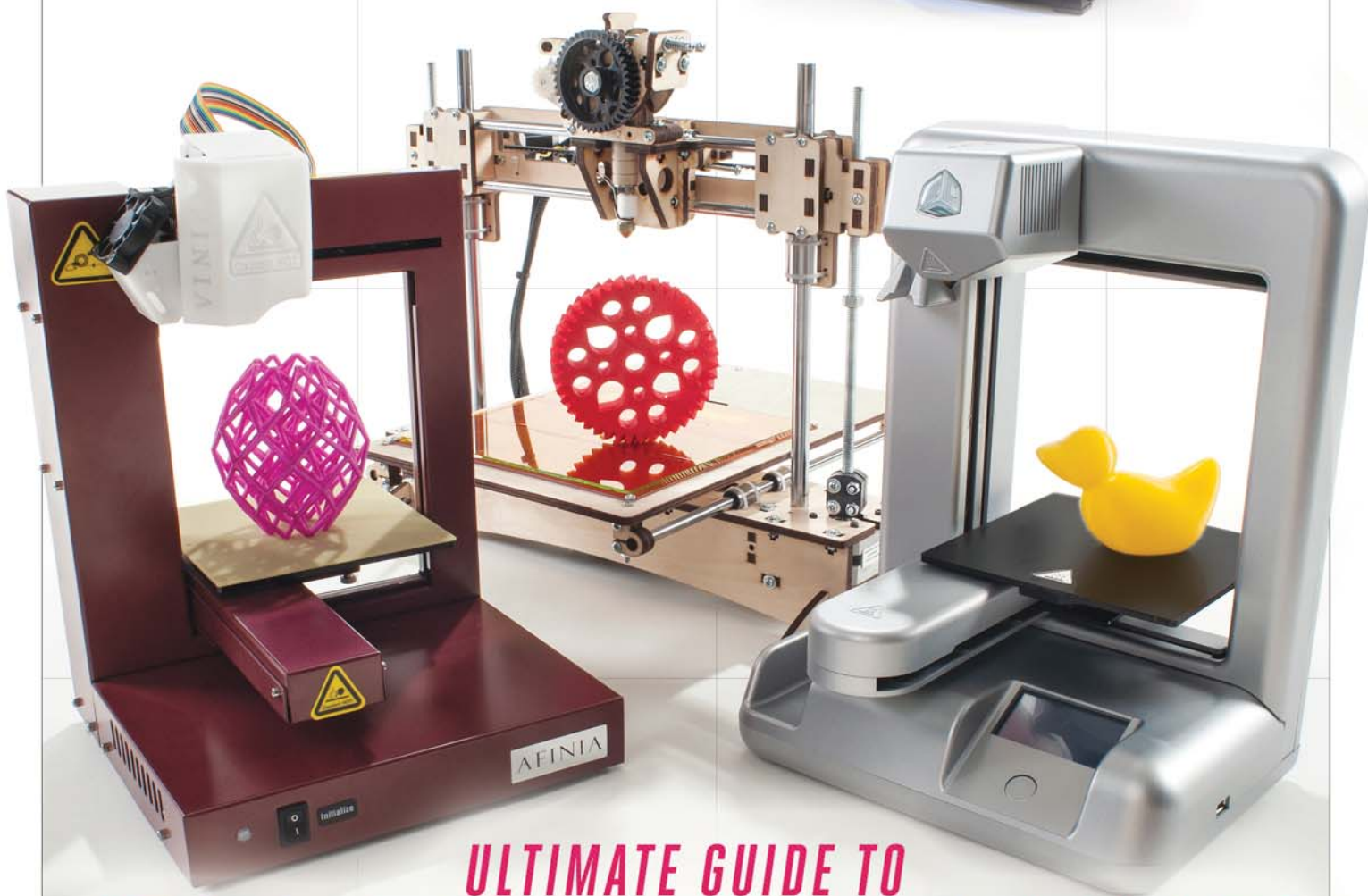
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Ultimate 3D Printer

BUYER'S GUIDE

Here's how we torture-tested and rated 15 machines.

WRITTEN
BY
**MATT
GRIFFIN**

WHAT MAKES A GREAT DESKTOP 3D PRINTER? In September, MAKE invited me to put together a team of reviewers from the 3D printing community to advise MAKE's readers about the state of the art of DIY 3D printing.

Our team investigated 15 of the most promising fused-filament fabrication (FFF) printers on the market — devices that melt and extrude plastic filament to form solid objects, layer by layer, the most popular method of 3D printing. We reached back to 2010 and into the future, previewing still-under-wraps machines weeks before their launch at World Maker Faire New York. But first we had the tough task of working out how to test and review these machines.

PERFORMANCE

What makes a successful print? Here are key questions from our testing sheet. Our ratings indicate that reviewers disagreed strongly (1) or somewhat (2), were neutral (3), or agreed somewhat (4) or strongly (5).

- » Print job horizontal surfaces were “true”/no rippling/level.
- » Top layers of horizontal surfaces “capped” successfully, without gaps.
- » Vertical surfaces were “true.”
- » Vertical surfaces lacked gaps.
- » Vertical surfaces lacked tool/layer-completion seams.
- » Print remained fixed on plate.
- » Registration of layers was consistently accurate.
- » Plastic was consistent color.
- » Overall, this machine was precise.
- » Layer height remained consistent.
- » Discernable detail resolution approximated vertical resolution.
- » Layer-height resolution allowed for organic curves and folds with minimal stair-stepping.
- » Scale accuracy: size and shape of resulting parts matched intention.
- » Machine could handle overhangs up to 45° with minimal dropped loops.
- » Machine accurately reproduced sharp corners.
- » Output had no ripples or wobbles.
- » Surfaces were clean and smooth in places the artist intended.
- » Machine was fast.
- » Machine interface was reliable.
- » Rarely had to retry failed parts.
- » Could hit print and the machine would work without babysitting.
- » Print could be removed easily with tools or by hand.
- » Post processing (cleanup, support/raft removal) was quick and easy.

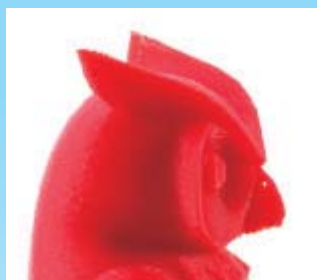


During the 3D Print Shop weekend, the MAKE offices became a vortex of 3D printers and the geeks who love them.

Every cresting wave in the alien invasion of the 3D printer into homes and maker-spaces — whether it's come from the factory floor, the academic laboratory, or the hobbyist's garage — has promised us the arrival of “the 3D printer industrial revolution.” The signs are clear. From the explosion of the RepRap movement after 2007, to the launch of the popular MakerBot Cupcake CNC kit in 2009, to Printbot and other crowdfunding mega-hits of 2011, there is tremendous interest in devices that arm individual inventors, designers, hackers, educators, and hobbyists with an affordable toolset to make anything, in plastic.

But there are two questions makers must ask themselves: Is this the moment to choose a printer and join the plastic revolution? And if so, which machine do I choose?

We wanted to avoid staging a shootout to assess printers in terms of winning and losing, strictly on the specs. First of all, the frontier days aren't over. Many of the more capable machines we reviewed are harder to use, meant for the intrepid maker who's eager to get under the hood (though there are consumer-oriented options now too, for those who'd rather not tinker). Also, while



THE HOLE IN THE OWL'S BEAK

During MAKE's 3D Print Shop weekend, we noticed something startling about the owl print we'd done on the Afinia H-Series. The model had a tiny hole all the way through the top of its beak. We went through the other machines' test prints, and none were successful in printing the nostrils on the owl. Since then I've asked other owners of 3D printers if they knew the owl had nostrils, and none of them had. Their printers haven't managed the through-hole either. The hole in the owl's beak — the holy grail of affordable home 3D printing.

—Gareth Branwyn

brilliant solutions have been brought to bear on mechanical design, the software tools are lagging, not only in toolpath generation (a challenging engineering problem) but also in usability (far less forgivable). Many of the machines that rely on open source hardware share these flawed software tools, and we're confident the user experience will improve as new talents continually contribute to improving them.

What core qualities does a maker look for in a 3D printer? We based a battery of test questions around four guiding principles:

- » A printer should be affordable for an individual to purchase and use regularly.
- » The hardware interface and software control tools should be easy to obtain, free or affordable, and documented for use.
- » The printer must produce pieces to suit the range of purposes that users create digital designs for: mechanical parts, product development, practical enclosures and mounting hardware, toys, scale models, and artistic/sculptural prints.
- » The machine should be worth a maker's time and money and should pull its weight on a workbench or desktop.

Tough demands, but ones that sharply distinguish DIY 3D printing from what's asked of industrial/commercial 3D printers.

In the early years, DIY 3D printers were balky and print jobs were limited to single, solid objects in one color of plastic. But a new wave is upon us. The quantity and diversity of DIY 3D printers that launched in 2012 are of a new order: they perform more reliably and tackle more sophisticated techniques. But do they work well right out of the gate, or do they require hours or even days of tuning and calibration?

The learning curve for operating some 3D printers can be steep. How deep should we dive into the forums and support resources in the pursuit of the capabilities of these machines? Should each of us bring our extensive background in operating other printers to bear on the machine at hand?

Grappling with these questions and believing strongly that vendors of DIY 3D printers need to better instruct users how to operate their machines, we settled on a compromise we described as the “Christmas Morning Challenge.” What's it really like for a first-timer to open the box, set up this machine, and get it to fabricate that first printed object of acceptable quality?

TESTING METHODOLOGY

To approximate the beginner's experience, each tester was a “first-timer” on the printer they were assigned, and approached the test as if they had limited access to other resources or customer support lines.

Each 3D printer was unboxed and set up — or assembled from parts in the case of the kit printers. Then each machine printed the same four test objects (pictured at right) using the manufacturer's default settings. In addition, we probed the capabilities of machines that were bigger, smarter, faster, or finer than their peers.

Each machine was then rated on a battery of questions, from ease of setup and calibration, to the quality of the hardware interface (if any) and software, to print quality, speed, and reliability. (Note that while manufacturers' claimed speeds vary wildly, in our default tests no machine was run faster than 80mm/sec.) See the full suite of questions at makezine.com/3dprinting.

We also invited printer vendors and their “superusers” to print the same objects and mail us their versions. We've shared these online at makezine.com/3dprinting, and we invite you to share your results too (see “Superusers: Participate!” below). As a result, we hope to provide balanced feedback that reflects the experiences of both first-time users and seasoned experts, and the true capabilities of each machine.

Read on to see what we found, but one thing became clear: while the field has further to go before the “revolution” offers desktop-grade printers suited to every home and workshop, there are a number of machines worthy of your serious attention. It's up to you to pinpoint which qualities are most important, how much time and money you want to spend, and what community of users suits you. If you're ready to start 3D printing, there's a printer ready for you here.

SUPERUSERS: PARTICIPATE!

Do you have one of the 3D printers in our test and want to share your prints of our test objects? Have a special trick or “pro tip” that might help others? Or perhaps you've tuned your slicing profile to perfection and can achieve models a newbie wouldn't believe? Please share your tips, files, and photos at makezine.com/3dprinting so that everyone in this high-energy, passionate community can benefit.

THE CHALLENGE PRINTS



SNAKE by Zomboe
thingiverse.com/thing:4743

This reinterpretation of a classic wooden toy features flexible ribs that are a great test for both horizontal accuracy on the plate (are the ribs evenly spaced and complete out to their tips?) and vertical registration (does each layer match perfectly with the one beneath?).



OWL STATUE
 by Tom Cushwa
thingiverse.com/thing:18218

Designer Cushwa borrowed stone-cutting techniques to render feathers and character features for this popular owl figurine and modeled them to look great on a well-tuned printer. Printers that choke on these details may not be suitable for character and sculptural work.



NAUTILUS GEARS by Misha T.
thingiverse.com/thing:27551

This model gives character to the classic snap-together gears that are a popular test object for 3D printers. It's quick to print, and you can tell instantly how well the machine reproduced the parts from how accurately the teeth mesh and the snaps snap, and whether the gears can rotate through more than one revolution without binding.



DIMENSION TORTURE TEST
 by Cliff L. Biffle
makezine.com/3dprinting

To create a real "torture test" – a model guaranteed to challenge all FFF printers – engineer Cliff L. Biffle built a Frankenstein's monster containing all the geometry we needed to see in one small package. Thin and fat features, slopes and overhangs, bolt holes with precise dimensions, arcs, and separate towers all conspire to push a machine to its limits.

TEAM OF TESTERS



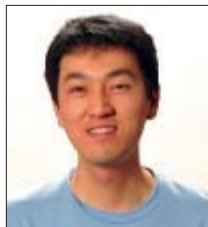
John Abella gets obsessive about hobbies. He currently owns three 3D printers.



Cliff L. Biffle is an engineer at Google and a member of Ace Monster Toys, a hackerspace in Oakland, Calif. He enjoys using science as a verb.



Gareth Branwyn is editorial director of MAKE. His master plan is to learn 3D printing so he can print replacement parts as his body falls apart with age.



Eric Chu is an engineering intern at MAKE. He enjoys yo-yos, robots, and fried rice.



Matthew Griffin is Adafruit Industries' community director. Formerly with MakerBot Industries, he's writing a book for O'Reilly on the 3D printing community.



Ethan Hartman is a customer service and documentation specialist for technology companies. He worked for MakerBot from 2009 until August 2012.



Lyra Levin builds things compulsively, preferably things she can climb on. She is currently in training to be a superhero.



Blake Maloof is a game designer at Toys for Bob (makers of *Skylanders*), and he sometimes writes about games for MAKE.



Brian Melani builds 120-pound robots in his free time. He is a MAKE engineering intern.



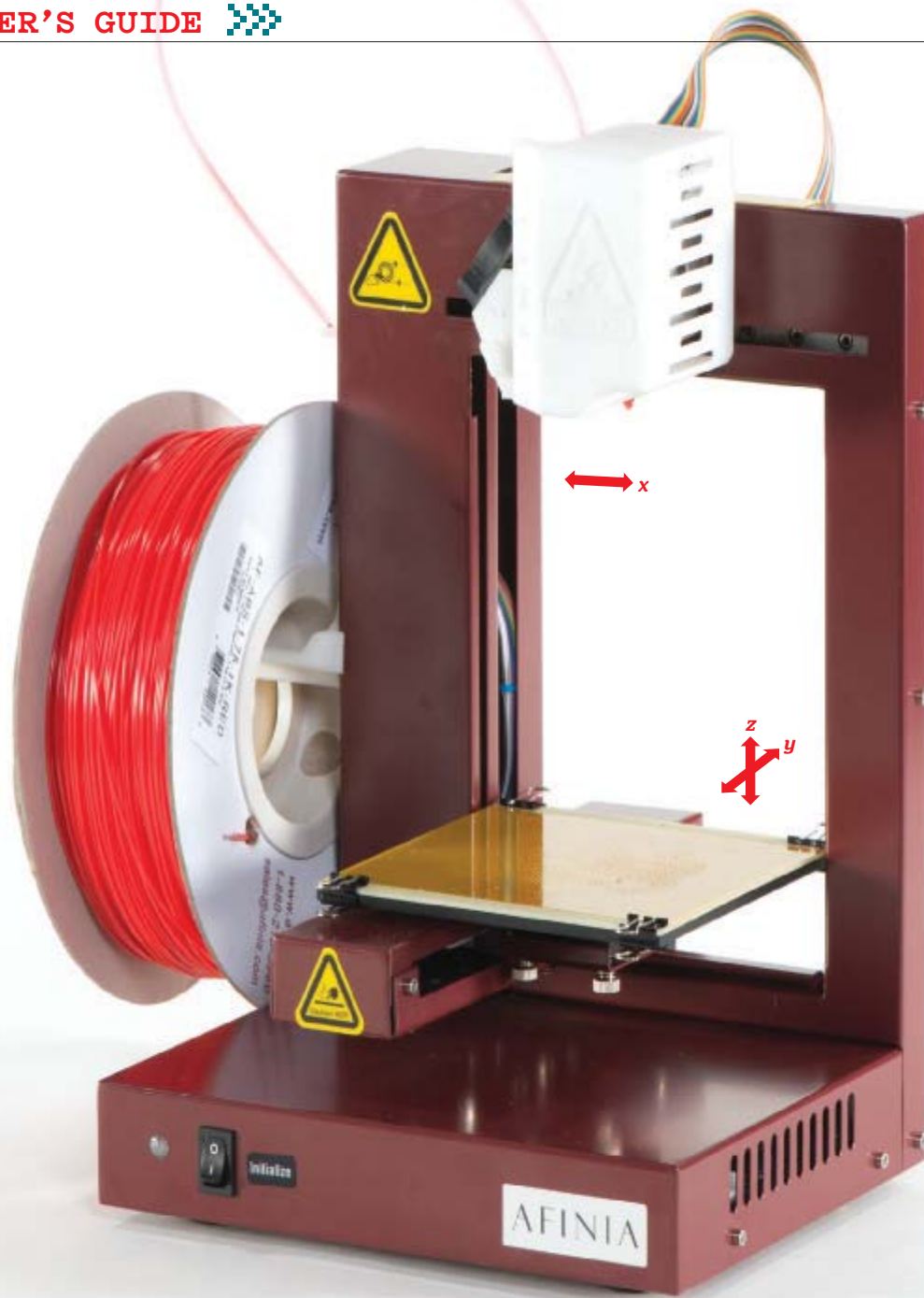
Emmanuel Mota is a creative director, filmmaker, photographer, and full-time geek. He got into 3D printing in 2012 when he built a RepRap from scratch.



Keith Ozar is a creative marketing professional from Brooklyn, NY. He empowers makers through special projects that highlight the potential of 3D printing.



Eric Weinhoffer is MAKE's product development engineer for the Maker Shed. He's been an owner-operator of 3D printers since interning at MakerBot in 2009.



» **Primo features** Heated platform, great print quality and software, U.S. tech support

- » **Print volume** 5.5"×5.5"×5.3"
- » **Print speed** 3-30mm³/sec
- » **Print material** ABS, PLA
- » **Resolution (z-axis)** 0.2mm
- » **Machine software** Afinia 3D
- » **Slicing software** Afinia 3D
- » **OS supported** Windows, Mac
- » **Open source?** No
- » **Price as tested** \$1,499 assembled
- » **Pedigree** PP3DP Up
- » **Print without PC?** Sort of ...

Afinia H-Series

Microboards Technology afinia.com

Easy to use, with feature-rich software and impressive print quality.

WRITTEN BY KEITH OZAR
 TESTED BY KEITH OZAR AND ERIC WEINHOFFER

THE COMPACT AFINIA H479 IS A VERSION OF PP3DP'S UP PLUS 3D printer, rebranded for the U.S. market. It's got a single extruder and runs via USB off Mac or Windows machines, with no onboard controls except an Initialize button and a flashing status indicator. But despite the no-frills hardware, it's a surprising little performer that's ideal for beginners.

SETUP

The printer's tidy size and appearance are appealing: it sits about 10"x10"x14" high on the desktop, weighs just 11lbs, and is sturdy for transport. It ships fully assembled and takes only a few minutes to set up. Loading the filament, leveling the platform, and calibrating the machine were easier than expected, thanks to documentation that's straightforward and easy to follow, with an in-depth manual and a one-page Quick Start Guide for those wanting to jump right in.

The status light tells you in a series of red and green flashes if the printer has been initialized, if it's ready to print, if the extruder is heating or extruding, and if it has started or stopped printing — but if you don't have the manual in front of you, this can be confusing. It's a constant reminder that the lack of an onboard control panel is a weak spot for this printer. The machine also makes a loud beeping sound as it begins initializing and printing, which reminded us of a truck backing up, though it prints quietly.

Using the proprietary software package Afinia 3D, you can add multiple objects to the same platform, choose to build with a raft, set variables for the support structure, and choose resolution and a variety of infill options. Just select the overhang angle beyond which you'd like to have support material, and the software automatically creates the support for any angle that exceeds it.

Once your design is to your liking, it's as easy as pressing Print. There's no need to deal with G-code or slicing software — it takes care of those elements for you. Although the software is "closed" and can be prone to crashing, its features are robust and relatively intuitive.

PERFORMANCE

Print quality was quite good — we were surprised by how great the first print looked (the snake), and subsequent prints like the owl statue confirmed it: sharp corners, clean overhangs, and true vertical and horizontal surfaces. Dimensional accuracy was off by about 1% on our torture-test object, with holes just slightly undersized, though this might be attributable to shrinkage of the ABS plastic.

The Afinia was reliable, too; we didn't have to babysit it or retry failed parts. The documentation mentions the capability of pausing mid-print to swap out filament and resume where the extruder left off, but we didn't get a chance to test it. This technique would be a great option if you wanted to print a multicolored object with a single extruder.

While this model is about the same size as the original Up released two years ago, its build volume is still decent-sized compared to today's DIY printers, about a 5½"-cubed range of motion. Both ABS and PLA filament can be used, and the printer comes with a 1.5lb ABS spool. (Afinia offers additional spools in natural, black, red, blue, yellow, and green, or you can buy from other manufacturers.) It also comes with work gloves and hand tools that include a woodcut knife, screws, scraper, pliers, brush, nozzle wrench, hex wrench, and tweezers.

Also provided are a set of FR-4 perf boards for the print surface that offered surprisingly successful printing adhesion, and could be cleaned easily using the included tools to push plastic up through the holes. The style of rafting and support offered by the software also help with both adhesion and removal.

Unfortunately, there is no SD card or USB flash drive on the Afinia. You can print from your computer via USB and then disconnect once the job has started printing, since the file now resides in the printer — but we'd prefer to be able to print totally untethered.

Also, the print speed was comparatively slow next to many of the more recently designed 3D printers we tested.

CONCLUSIONS

The Afinia H-Series 3D printer stood out as one of our favorite 3D printers in the challenge. Straight out of the box, using the default 0.2mm resolution settings (about 0.008" or 8 mils), we printed some of the best-looking examples of the challenge prints.

While there are limitations to how far you can tune, tweak, or tinker with a closed-box machine, the Afinia offered the best printing quality with the least amount of effort, overshadowing any of its limitations.

HOW IT COMPARES

Setup	5/5
Documentation	5/5
Ease of Use	4/5
Hardware User Interface	3/5
Machine Software	4/5
Slicing Software	5/5
Speed	2/5
Reliability	5/5
Print Quality	5/5
Accuracy	5/5
Support/Overhangs	5/5
Noise	4/5
Value	4/5

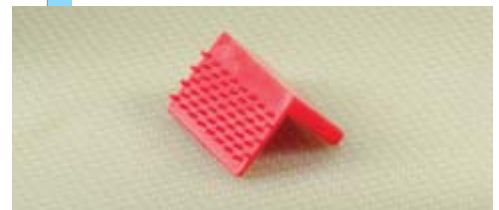
PRO TIPS

Preheat the platform 15 minutes to prevent ABS prints from warping.

If the ABS looks white where you remove the raft or support, warm it with a heat gun to regain color.

Don't be limited by platform size. To build large objects, slice models creatively and glue them, create snap-together joints, or articulate them with moving joints or gears.

THE DETAILS



The unique perf-board build platform performs well, and the software slices, generates support, duplicates, and places models for printing — all automatically.

The Standouts

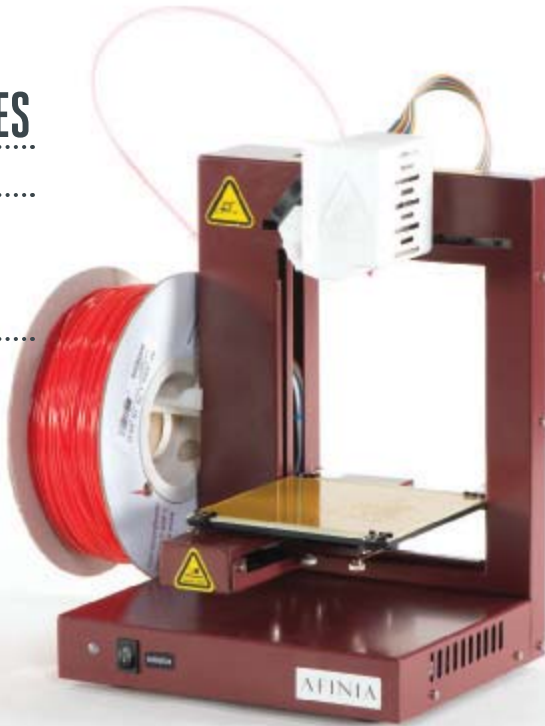
Clear winners in every category.

BEST OVERALL EXPERIENCE

AFINIA H-SERIES

Review on page 44

Also won for
Easiest Setup, and
Easiest to Use
(tied with Cube)



AVAILABLE AT
MAKERSHED.COM



BEST OPEN HARDWARE

ULTIMAKER

Review on page 70

Also won for Most Accurate
and Fastest

PREMIUM



AVAILABLE AT
MAKERSHED.COM

BEST IN CLASS REPLICATOR 2

Review on page 62

Runner-up for Most Accurate

MIDRANGE



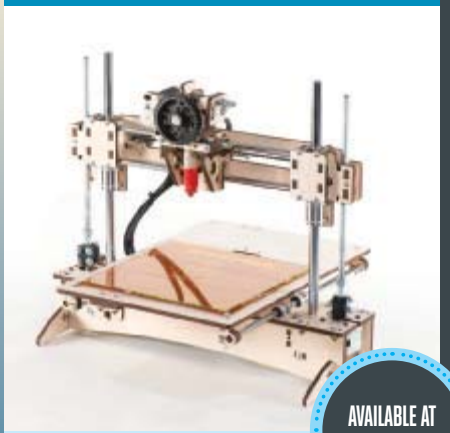
AVAILABLE AT
MAKERSHED.COM

BEST IN CLASS TYPE A SERIES 1

Review on page 68

Runner-up for Most Accurate

ENTRY LEVEL



AVAILABLE AT
MAKERSHED.COM

BEST IN CLASS PRINTRBOT LC

Review on page 58