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Review

Thermoplastics and Photopolymer Desktop 3D Printing System Selection Criteria Based on Technical Specifications and Performances for Instructional Applications

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Abstract: With the advancement of additive manufacturing technologies in their material processing methodologies and variety of material selection, 3D printers are widely used in both academics and industries for various applications. It is no longer rare to have a portable and small desktop 3D printer and manufacture your own designs in a few hours. Desktop 3D printers vary in their functions, prices, materials used, and applications. Among many desktop 3D printers with various features, it is often challenging to select the best one for target applications and usages. In this paper, commercially available and carefully selected thermoplastic and photopolymer desktop 3D printers are introduced, and some representative models' specifications and performances are compared with each other for user selection with respect to instructional applications. This paper aims to provide beginner-level or advanced-level end-users of desktop 3D printers with basic knowledge, selection criteria, a comprehensive overview of 3D printing technologies, and their technical features, helping them to evaluate and select the right 3D printers for a wide range of applications.

Keywords: 3D printers; desktop; additive manufacturing; selection criteria; survey; non-metal; materials; processing

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1. Introduction

A 3D printer is a computer-aided manufacturing device that creates three-dimensional objects by joining or solidifying custom materials [1,2]. Recent advancements in 3D manufacturing, namely 3D printing or additive manufacturing and the development of new material and process optimization, have brought a new paradigm of manufacturing in nearly all disciplines in science and engineering subjects [2,3]. Three-dimensional printers these days have been widely spread to academics and end-users or public consumers. Therefore, any user who knows computer-aided design (CAD) through software, such as SolidWorks and Autodesk Inventor, can send files to 3D printers and see your designed objects in a few hours [4–14]. Though objects printed on your desk are far from engineered structures, it has opened a new paradigm of designing and implementing your own designs even without an engineering background [15–19]. In this paper, we introduce overviews of major thermoplastic and photopolymer desktop 3D printers and their selection criteria based on specifications and important performance parameters and characteristics for end-users targeted in instructional applications. Through these rigorous investigations of recent thermoplastic and photopolymer desktop 3D printers, this paper could be used as a "handbook" for users of various backgrounds.

2. Background

Three-dimensional printing, also referred to as additive manufacturing, is a new material processing technology that allows creating a physical 3D object from computer-aided modeling tools, such as CAD [4,5,8,12,13,16]. It started in the 1980s as a way to make prototype objects faster and cheaper [20]. In 1981, Hideo Kodama made a rapid-prototyping system using photopolymers. Three years later, Charles Hull invented stereolithography, a liquid photopolymer, that when hit with a UV laser, turns the liquid into a solid. This is called Stereolithographic apparatus (SLA). That same year, a startup company used a powder instead of a liquid, creating the selective laser sintering machine (SLS). At the dawn of the millennium, Wake Forest Institute for Regenerative Medicine printed synthetic scaffolds of a human bladder and then coated them with the cells for a human implant. Shortly after, different institutions fabricated a functional miniature kidney, prosthetic leg and bio-printed the first blood vessels [20].

Nowadays, 3D printers are used by professionals to make marketable objects [19,21]. Three-dimensional printers use software to slice a digital model and interpret the parameters into G-code, a language that the printer understands [15,22,23]. These printers are now commonly used in various fields to make custom models at a lower cost [8,18]. By virtue of the portability, easiness and low-cost maintenance and acquirement, instructional applications are highlighted by teachers and educators for their students in various subjects [22–24]. There are three classifications of 3D printers. They are desktop, professional, and industrial [4,8,18].

When it comes to desktop printers, the 3D printed objects produced are still not on par with industry standards for specific items that require a particular strength and durability [25]. It is interesting to know what desktop printers exit and how end-users select proper ones for their own applications.

2.1. Types of Standard AM (Additive Manufacturing) Processes

ASTM (American Society of Testing and Materials) generically defines seven classifications for additive manufacturing, namely [26,27] (1) Binder Jetting (BJ) [28–31], (2) Directed Energy Deposition (DED) [32–35], (3) Material Extrusion (ME) [36–39], (4) Material Jetting (MJ) [40–43], (5) Powder Bed Fusion (PBF) [44–47], (6) Sheet Lamination (SL) [48–51], and (7) Vat Photopolymerization (VP) [52–55]. Among these, the authors of this paper select ME types, called 3D printing, and we introduce nine different and popularly adapted methods in thermoplastics and photopolymer desktop 3D printing processes.

- **Fused Deposition Modeling (FDM or FFF)**: It is a material extrusion technique that prints plastic layer by layer at various thicknesses, speeds, and temperatures [56–59]. Some of notable works conducted [58,59] have shown the advantageous features of FFF technology with enhanced features by reducing printing time and waste through removing additional materials' needs for the supporting structure.
- **Stereolithography Apparatus (SLA)**: It is known its top accuracy and precision [60]. It converts liquid photopolymers into 3D objects, and the plastic is heated into a semi-liquid form, which hardens on contact with a UV laser. The object is then washed and cured to make it stronger and more stable. Some representative works are introduced in [8,56].
- **Digital Light Processing**: DLP is the oldest 3D printing method, and much like the SLA method, it uses a liquid plastic resin and an arc lamp (instead of a UV laser) to solidify the material to form the object. It is faster than SLA because it creates entire layers at once, whereas SLA has to draw out each layer [1,2]. An application for silk hydrogel printing is introduced in [61].
- **Selective Laser Sintering (SLS):** SLS technology uses a high-powered carbon dioxide laser to fuse metal (or nylon powder, ceramics, and glass) by partly melting the particles together. Since un-sintered material surrounds the print, this method does not require printed supports for stability. The un-sintered material is removed manually after the printing is carried out [62]. Due to its advanced and selective features for source selection, SLS is used for various applications in the medical field [63,64].

- **Selective Laser Melting (SLM)**: SLM also uses a high-powered laser that melts and welds metallic powders together by layer. The unused material is removed after the object is finished printing. SLM completely melts the powder, resulting in a more robust finished product over SLS [8]. SLM is heavily used in industrial applications for its complex geometry structure without space limitations [65,66]
- **Electron Beam Melting (EBM)**: EBM is similar to SLM, but instead of a laser, it uses a powerful electron beam in a vacuum to print metal objects. The product is solid and dense [8]. Some of its applications are introduced in detail in references [67,68]
- **Laminated Object Manufacturing (LOM)**: LOM is a method that fuses plastic or paper using heat and pressure with a laser and a roller. It is one of the fastest and most affordable methods for 3D printing [18]. With the advancement of rapid processing requirements and material selection, printing for materials such as composite and ceramic adapts LOM [69].
- **Binder Jetting (BJ)**: BJ was invented at MIT. It uses two types of materials (powder-based material and a bonding agent) to build objects. The materials can be ceramics, metals, sand, and plastics [8]. Binder Jetting is faster and more cost-effective than many 3D printing technologies. Binder Jetting machines can print quickly by using multiple heads to jet binding material simultaneously, turning out tens or even hundreds of parts in a single build. However, metal parts produced by Binder Jetting have inferior mechanical properties than DMLS/SLM parts. Additionally, the choice of materials used in Binder Jetting is limited [28–31,70,71]
- **Material Jetting Polyjet (MJ)**: The MJ method uses molten wax as the material to make molds and casts. A UV light helps the layers to cure, and a gel-like material is used for supports. The gel is removed afterward by hand or water jets [1]. MJ can produce smoother parts and surfaces than injection molding that guarantees very high dimensional accuracy. In addition, parts printed by MJ could have homogeneous mechanical and thermal properties. However, they are poor in mechanical properties so that parts cannot be used for functional prototypes [40–43].

2.2. Common Thermoplastic and Photopolymer Materials of Desktop 3D Printers

Below is the list of the commonly used thermoplastic and photopolymer materials in desktop 3D printers. Most of them are plastic polymers, and they mostly come in filament form. Excluded here are composite, carbon fiber, metal-based, wood, nylon, and silicone materials. Some of the materials used in specific printers use brand names, such as flex or Ninjaflex, and they fall one of the material lists below [56]:

- Acrylonitrile Butadiene Styrene (ABS);
- Polylactic Acid (PLA);
- Thermoplastic Polyurethane (TPU);
- Thermoplastic Elastomers (TPE);
- Polyethylene Terephthalate (PET);
- Polycarbonate Acrylonitrile Butadiene Styrene (PC-ABS);
- Chlorinated Polyethylene (CPE);
- Polyvinyl Alcohol (PVA);
- High Impact Polystyrene Sheet (HOPS);
- Acrylonitrile Styrene Acrylate (ASA).

3. Industry vs. Desktop 3D Printers

3.1. Printers for Industry

The main difference between industrial and desktop printers is print size, machine size, cost, and materials used. Industry printers have better accuracy, thicker layers, bigger build volumes, and a wider range of prices but are still more expensive than desktop printers [8]. Therefore, the major applications in industrial 3D printers are replacing conventional manufacturing processes such as parts with highly complicated geometry and requiring a certain level of mechanical properties. In addition, industrial printers always print with support to achieve better accuracy. Industrial printers also work with more expensive materials to produce better quality prints [18].

3.2. Desktop Printers

Desktop printers are not typically concerned with durability and strength. They are smaller and cheaper than industry printers. Mostly used for prototyping concept designs and replacing parts that don't require strength or durability. The accuracy of desktop 3D printers is often lower than industrial printers. This paper has selected five major commercially available 3D printer manufacturers and their iconic models to compare. These days, users' choice of printers is more individual based on their preference than satisfying certain requirements in desktop printers [1,2,8,13,18,20,58,64].

3.3. Challenges in Desktop Printers

As mentioned above in Section 3.1, desktop 3D printers are quite different from industry ones in their size, accuracy, materials, and so on [1,2,8,13,18,20,58,64]. Some of the major challenges in desktop 3D printers are summarized below.

- **Lack of formal standards**: Due to the usage of desktop printers mainly for proof-of-concept models from CAD or similar purposes, standardization in material properties, extruder speed, the manufacturing process has not been recognized and established yet.
- **Limited repeatability**: Unlike molding in the conventional manufacturing process, various processing parameters, such as speed, temperature, material characteristics, and inherited characteristics of additive manufacturing, do not guarantee as repetitive results as conventional ones.
- **Software development and capabilities**: Development software is not often provided open-source, limiting the capabilities of tuning in system parameters for precise control in hardware and material processing.
- **Limited selection of materials**: Comparatively small and simple hardware in the printers also limits the number of materials to process. Typical desktop printers can process up to five different materials while industry ones are above 10 or more simultaneously or separately.
- **Low-resolution output**: Similarly extended to limited repeatability, desktop printers do not require mechanical properties of prints but while simple and rapid material processing.

4. Comparison of Desktop 3D Printers

Here we compare five carefully selected and commercially available desktop 3D printer manufacturers and representative models in each. This survey aims to provide information on proper selection criteria depending on applications and end-users' needs. The comparing attributes are the build size, nozzle size, layer height, printing speed, file format, printing software, nozzle and bed temperature, power supply, features, price, and compatible filaments or materials of all these printers. This comparison is to find the best printer for our research purposes [56]. As shown in Table 1, different manufacturers are slightly different in most of the attributes. Additionally, it is noted that these desktop 3D printers are limited in customization. For example, most of the printers in Table 1 are allowed to change the speed of the extruder moving in directions. This could mean the number of materials and cooling speed and entire processing time could also vary. Each model is also described in pros and cons and market price so that end-users could choose the most suitable printers for their application and within their budget.

Table 1. Comparison of 5 representative desktop 3D printer manufacturers.

3D Printers					
Printer Name Model No.	**Printing Material**	**Customization**	**Pros**	**Cons**	**Price in USD**
Creality Cr-10s	ABS, PLA, TPU	x,y,z movement	Price, size, dual extruder option for a higher price	Customizability, challenging to print with ABS and TPU, No original software, no enclosure	400–500
Prusa i3 mk3	ABS, PLA, Flex, PET, composite, nylon, PC-ABS	x,y,z movement	Automatic bed leveling, price, features, fast heating	No enclosure	799–999
Makerbot	ABS, PLA, filaFlex	z movement	Auto bed leveling has a model with dual extrusion with PVA printing and enclosure	Not many filament options need to print raft for better removal	2799–6499
Ultimaker	ABS, PLA, TPU, CPE, PVA, PC, Nylon	x,y,z movement, and z offset through software	Print supports in separate material for easy separation, heated bed, auto bed leveling, enclosed, dual extrusion, quiet	Longer print time	2500–6000
Formlabs	Resin (tough, rigid, flexi, castable wax, ceramic, elastic, durable)	z movement, x-y scaling	Cleaner prints	Messy cleanup	3350

Table 1 summarizes important attributes in printer selection, including price ranges. Desktop 3D printers are limited in customization in the hardware itself, unlike industrial ones. The majority of printer manufacturers use similar materials except for Formlabs [72], as shown. The next Section 4.1. describes each manufacturer's representative models in detail. Essential features and cons are described as well that are mainly provided by the manufacturers.

4.1. Creality 3D

We here show three representative models from Creality: (1) Cr-10s, (2) Cr-10s pro, and (3) Ender 3. Cr-10 pro is an upgraded version of Cr-10s. Their details including features, shortcoming, and prices are summarized in Tables 2–5 [73].

4.1.1. Creality 3D: Cr-10s

The Creality 3D Cr-10 won Best 3D Printer Under USD 500 from All3DP.com [57], a reputable site that reviews and ranks most 3D printers on the market. This printer is an upgrade from the Cr-10 because it adds a filament sensor and other improvements.

4.1.2. Creality: Cr-10s Pro

The Creality 3D Cr-10s has upgraded features compared to the previous model, Cr-10 shown in Table 3. Mainly its noise, heating time have been improved.

4.1.3. Creality: Ender 3:

The Ender 3 was voted Best Printer Under USD 200 in All3DP.com [57]. It is the third installment in the ender series from Creality [73]. It has the same functions as the Cr-10s pro, but it has a smaller form factor and is cheaper to appeal to the consumer on a budget as shown in Table 4.

Table 2. Descriptions of Creality 3D Cr-10 Desktop 3D Printer.

Power Supply	**Input: 100–240 V 5.9 A 50/60 Hz Output: 24 V 21 A 480 W**
Materials	1.75 mm, PLA, ABS, Wood, TPU, gradient color, carbon fiber
Features	Filament run-out detection Outage recovery Aluminum frame Requires assembly MK8 nozzle extrusion structure; different nozzle sizes available Printing accuracy: ±0.1 mm
Cons	The extruder is placed awkwardly on the *z*-axis. The filament holder is prone to tangling. The print preparation is tedious. The feet of the printers do not mitigate the print bed inertia. The heat bed takes a long time to reach the desired temperature. The filament that requires consistent heat is difficult to print with this printer [2].
Price	USD 439.99

Table 3. Descriptions of Creality 3D Cr-10s Pro Desktop 3D Printer.

Power Supply	**Input 100–240 V 50/60 Hz Output: DC 24 V**
Materials	1.75 mm PLA, ABS, Wood, TPU, gradient color, carbon fiber etc.
Features	All the features of Cr-10s Automatic matrix mesh leveling Quieter Quick heating print bed Touchscreen Double gear extrusion
Price	USD 629

Table 4. Descriptions of Creality 3D Ender 3 Desktop 3D Printer.

Power Supply	**Input: AC 100–265 V 50–60 Hz Output: DC 24 V 15 A 360 W**
Materials	1.75mm PLA, ABS, Wood, TPU, gradient color, carbon fiber, etc.
Features	Magnetic build surface plate Quick heating hotbed Resume print function Precision: 1 mm
Cons	This printer needs assembly. It has a slight wobble from an uneven base that makes it hard to level. Some adhesion is needed to obtain the prints to stick to the bed. This printer needs manual calibration. The bed is flimsy and requires re-leveling.
Price	USD 229

Table 5. Descriptions of Creality 3D Cr-X Desktop 3D Printer.

Power Supply	Input: 100–240 V 5.9 A 50/60 Hz Output: 24 V 21 A 480 W
Materials	1.75 mm PLA, ABS, TPU, Copper, Wood, Carbon Fiber, Gradient Color c.
Features	Body Structure: Imported V-Slot Aluminum Bearings. Two-color printing Touchscreen Carboloy silicon printing platform Dual fan cooling Support water-soluble filaments
Cons	The Cr-X requires a large power supply. The bed takes a long time to reach the desired temperature. It is difficult to print with a filament that needs consistent heat, such as ABS. The preparation for setting up the printer can be tedious. The feet of the printer do not mitigate the inertia of the print bed while its printing.
Price	USD 719

4.1.4. Creality: Cr–X

The *Cr-X* is the first printer from Creality that is capable of printing two colors at a time. It uses two extruders to create multicolored prints instead of the competition who uses one extruder resulting in a lot of wasted material.

The Creality 3D Cr-X is the final version of Creality series. The main features including dual color printing and user interface have been added as shown in Table 5.

4.2. Prusa: i3 MK3

The Prusa 3D printer won Best 3D Printer Overall from ALL3DP [57] and was the winner of the 3D Printing Industry Awards personal 3D printer of the year award in 2018 [74]. It is also able to be manually upgraded into a multicolored printer through a kit that Prusa [75] sells on their website. However, since it prints out the same extruder, the printer would waste a lot of material trying to purge the nozzle of the previous color shown in Table 6.

4.3. Makerbot

4.3.1. Makerbot: Method

The Method is Makerbot's first 3D printer that can print soluble material [76]. The supports on printed objects can be easily removed by submerging the print in water. The Method is wholly enclosed and includes an air filter to keep the fumes from burning the filament inside as shown Table 7.

4.3.2. Makerbot: Replicator+

The Replicator+ is the second iteration in the replicator series from Makerbot [77,78]. It is one of the cheapest from Makerbot even though it is not cheap at all. The upgrade that this model has over the first is a larger, bendable build plate to improve the removal of the print from the bed as shown in Table 8.

Table 6. Descriptions of Prusa i3 *MK3* Desktop 3D Printer.

Power Supply	80 W/ABS Settings: 120 W
Materials	PLA, ABS, PET, HIPS, Flex PP, Ninjaflex, Laywood, Laybrick, Nylon, Bamboofill, Bronzefill, ASA, T-Glase, Carbon-fibers enhanced filaments, Polycarbonates
Features	Removable heat-bed Aluminum frame Quieter than 99% of available printers and faster 3d printing Print recovery and a filament sensor Shifted layer detection Double gear extrusion Temperature monitor probes E3d V6 nozzle Automatic mesh bed leveling Heat-bed with cold corners compensation–for warp-less 3D printing from any material Automatic skew axes compensation Hassle-free PEI print surface-no glass, no glue, no ABS juice Easy multicolor printing based on layer height 1 kg (2 lbs) silver PLA filament included
Cons	The filament sensor is buggy. The bed needs help with adhesion. The quality of the 3D printed components is not as good. There are frequent updates to keep track of.
Price	USD 749 or USD 999

Table 7. Descriptions of Makerbot Method Desktop 3D Printer.

Power Supply	100–240 V 4 A, 50–60 Hz 400 W Max.
Materials	PLA, Tough, PVA PETG, more to come
Features	Accuracy: $\pm$ 0.2 mm Industrial Reliability and precision Up to 2x faster than desktop printers. 21 onboard sensors Wifi connectivity 25 compatible cad file types Touchscreen Product dimensions: 43.7 L $\times$ 41.3 W $\times$ 64.9 H cm /17.2 $\times$ 16.3 $\times$ 25.6 in Frame construction: Aluminum Die-Cast Base Extruded Aluminum Uprights Steel Weldment Gantry Frame Temperature control: Circulating Heated Chamber Flexible Steel Build Plate Reusable Grip Surface Camera resolution: 640 $\times$ 480 pixels 21 sensors including: (1) DRAWER Temperature Humidity Control Material Detection RFID (2) PERFORMANCE EXTRUDERS Temperature Material Detection Encoder (Jam Detection) (3) PRINTER Lid–Open/Closed Door–Open/Closed Temperature Sensors–Heated Chamber Calibration Sensors (4) Automatic Z Calibration, Automatic Nozzle Calibration, Automatic Material Loading
Cons	The build size of the method is relatively small. There are cheaper alternatives being offered that also produce professional prints. The dual extruders are tricky to calibrate and maintain.
Price	USD 6499

Table 8. Descriptions of Makerbot Replicator+ Desktop 3D Printer.

Power Supply	**100–240 V, 50–60 Hz 0.76–0.43 A**
Materials	1.75 mm (0.069 in) MakerBot PLA Material-Large Spool, Small Spool MakerBot Tough Material-Large Spool, Additional materials such as bronzefill, copperfill, and woodfill,
Features	PC ABS with Powder-Coated Steel Reinforcements Aluminum Casting and Extrusions for Motion Components Grip Surface Build Plate Leveling Factory Leveled Stepper Motors 1.8° step angle with 1/16 micro-stepping XY Positioning Precision 11 Microns (0.0004 IN) Z Positioning Precision 2.5 Microns (0.0001 IN) CAMERA: 640 × 480
Price	USD 2799

4.3.3. Makerbot: Replicator z18

It was voted Best Industrial 3D Printer of 2019 by business.com [77]. They say that the PLA material that Makerbot makes for their printers is comparable in hardness with other material types, such as ABS. This printer is only optimized for PLA prints [15,79] (Table 9).

Table 9. Descriptions of Makerbot Replicator z18 Desktop 3D Printer.

Power Supply	**100–240 V; 5.4–2.2 A; 50/60 Hz; 350 W**
Materials	1.75 mm (0.069 IN) MakerBot PLA Material-Large Spool, Small Spool MakerBot Tough Material-Large Spool, Additional materials such as bronzefill, copperfill, and woodfill
Features	Construction Powder-Coated steel with PC-ABS and Aluminum Composite Material Build Surface Injection-molded PC ABS Stepper Motors 1.8° step angle with 1/16 micro-stepping XY Positioning Precision 11 Microns [0.0004 IN] Z Positioning Precision 2.5 Microns [0.0001 IN] CAMERA 320 × 240Cons:
Cons	The MakerBot cannot make supports from a different material than the printed object. It is also difficult to remove the printed object from the print bed without damage.
Price	USD 6499

4.3.4. Makerbot: Ultimaker 3

The Ultimaker 3 is the third rendition of the Ultimaker 3D printers. It includes two extruders to print different types of materials at the same time. It boasts a vast amount of filament types and colors that it is compatible with the printer [80]. There also is an Ultimaker 3 extended that extends the z-axis build volume for larger prints as shown in Table 10 below.

Table 10. Descriptions of Makerbot Ultimaker 3 Desktop 3D Printer.

Power Supply	Input 100–240 V 4A, 50–60 Hz 221 W Max. Output 24 V DC, 9.2 A
Materials	2.85 mm; Supported materials Nylon, PLA, ABS, CPE, CPE+, PVA, PC, TPU 95A, PP, and Breakaway
Features	Dual extrusion: 197 × 215 × 200 mm build size 0.25 mm nozzle: 150–60 micron 0.4 mm nozzle: 200–20 micron 0.8 mm nozzle: 600–20 micron Assembly type Pre-assembled Build Active plate leveling Print technology Fused filament fabrication (FFF) Dual extrusion print head Swappable print cores Dual geared feeder XYZ resolution 12.5, 12.5, 2.5 micron Nozzle heat up time < 2 min Build plate heat up time < 4 min Operating sound 50 dBA Operating ambient temperature 15 °C to 32 °C (59 °F to 89 °F) Nonoperating temperature 0 °C to 32 °C (32 °F to 89 °F)
Cons	The front of the printer is open. The spool holders are poorly positioned. The glass plate release system is fiddly. The design is boring
Price	USD 3495

4.3.5. Makerbot: Ultimaker S5

It was voted Best Dual Extruder 3D printer by all3DP.com [57] and Editor's choice from PCMag.com [75]. It is completely enclosed with an air filter to capture the fumes of melting the plastic. It features Dual extrusion and a wide variety of filament types and colors, just like the previous versions. Some details are shown in the Table 11 below.

4.4. Formlabs

Formlabs: Form 2

The Form 2 produced by Formlabs prints with different types of resin material. This type of printing is called SLA. It uses a laser instead of an extruder to harden the liquid resin into the desired shape. This type of laser process eliminates the braking points that are created when printing layer by layer with other 3D printers [72].

There is no printing without post-processing. It is slow compared to the other printers. The support structures are very dense. Changing the resin is a trivial task. The printing materials are expensive. The price range is about USD 3500.

4.5. T3D

A 3D printer recently launched by T3D company is a resin-based 3D printer and the first mobile multifunction 3D printer. It can print directly from smartphones or tablets. Some of the major features include (1) PLA and ABS materials for printing, (2) 160 × 76 × 85 mm build size, (3) minimum layer thickness of 0.1 mm, and (4) price raged around USD 300.00 [82].

Table 11. Descriptions of Makerbot Ultimaker *S5* Desktop 3D Printer.

Power Supply	**24 V DC @ 9.2 AMPS, 100–240V/6A/50–60Hz/500 W Max**
Materials	2.85 mm (1122 in); Optimized for PLA, Tough PLA, Nylon, ABS, CPE, CPE+, PC, TPU 95A, PP, PVA, Breakaway
Features	0.25 mm Print Core: 60–150 microns; 0.4 mm Print Core: 20–200 microns; 0.8 mm Print Core: 20–600 microns Printer Dimensions (including Bowden tube/filament spool holder): 49.5 × 58.5 × 78 cm (19.48 × 23.03 × 30.7 in) Included Filament: Tough PLA Black 750 g spool, PVA 750 g spool Included Spare Parts: 2 × 0.4 mm AA build material print core, 1 × 0.4 mm BB support material print core Included Accessories: Spool holder Glass build plate Glue stick Power cable Ethernet cable USB drive Grease (for z-screw lubrication) Sewing Machine Oil (for printhead rod lubrication) Hex screwdriver 2 mm XY calibration sheets 3× Silicone nozzle covers XY Positioning Precision: 6.9 microns Z Positioning Precision: 2.5 microns Please Note: PVA soluble support material only works in combination with PLA, CPE, and nylon build materials NFC system to automatically detect material type with official Ultimaker filament Open filament system also allows printing of 3rd party filament Print Technology: FFF Print Head: Dual-extrusion head with an auto-nozzle lifting system Swappable print cores (maximum 280 C) Build Platform: Heated glass build plate (maximum 140 C) Bed Leveling: Active Operating Temperature: 15–32 C (60–90 F), 10–90% relative humidity (non-condensing) Average Operation Noise: 50 dBA Storage Temperature: 0–32 C (32–90 F)
Cons	The Ultimaker *s5* is expensive and difficult to print with certain types of filaments. The camera feed freezes, and it has a longer print time than other printers [81]
Price	USD 5995

5. Specifications of Desktop 3D Printers for Selection Criteria

Different from features and functions, important terms that determine printers are specifications. Below is the summary of them as well as tabulated in Table 12.

- Printing Speed: Speed that the printer moves while extruding;
- File Format: The file types that the printer recognizes;
- Printing Software: The splicing software that the printer is compatible with;
- Nozzle Temp: Maximum temperature that the nozzle will reach;
- Bed Temp: Maximum Temperature that the heat bead will reach;
- Power Supply: The amount of input and output voltage the printer requires to work;
- Filaments: The types of materials that are compatible with the printer;
- Features: The unique capabilities the printer has to offer;
- Price: The amount of money the printer costs.

Table 12. Specifications of Desktop 3D Printers.

		Build Size	Layer Height	Printing Speed	File Format	Printing Software	Nozzle Temp. in C°	Bed Temp. in C°
Creality	Cr-10s	300 × 300 × 400 mm	0.1–0.4 mm	Normal: 80 mm/s, Max.: 200 mm/s Filament	STL, OBJ, G-Code,	CURA, simplify 3D, Repetier-Host	260 max	110 max
	Cr-10s pro	300 × 300 × 400 mm	0.1–0.4 mm	<180 mm/s, normal: 30–60 mm/s	STL, OBJ, G-Code	CURA, simplify 3D, Repetier-Host	<260	<110
	Ender 3	220 × 220 × 250 mm	0.1–0.4 mm	180 mm/s	STL, OBJ, G-Code	CURA, simplify 3D, Repetier-Host	255	110
	Cr-X	300 × 300 × 400 mm	0.1–0.4 mm	Normal: 80 mm/s, Max.: 100 mm/s	STL, OBJ, G-Code, JPG	CURA, simplify 3D, Repetier-Host	<260	<110
Prusa	I3 mk3	250 × 210 × 210 mm	0.05–0.35 mm	30–200 mm/s	STL, OBJ, G-Code, JPG	Simplify3D, Cura, Slic3r	300	120
Makerbot	Method	190 × 190 × 196 mm	20–400 microns	Up to 500 mm/s	makerbot, STL, OBJ, G-Code,	MakerBot Print, MakerBot Mobile	N/A	N/A
	Replicator+	295 × 195 × 165 mm	100 microns	175 mm/s max	Makerbot, STL, OBJ	MakerBot Print Software, MakerBot Mobile	N/A	N/A
	Z18	300 × 305 × 457 mm	100 microns	175 mm/s max	STL, OBJ	MakerBot Print Software, MakerBot Mobile	N/A	N/A
Ultimaker	3	215 × 215 × 200 mm	20–200 microns	<24 mm^3/s; 30 to 300 mm/s	STL, OBJ, X3D, 3MF, BMP, GIF, JPG, PNG	Ultimaker Cura Cura connect	180–280	20–100
	S5	330 × 240 × 300 mm	20–600 microns	<24 mm^3/s; 30–300 mm/s	STL, OBJ, X3D, 3MF, BMP, GIF, JPG, PNG	Ultimaker Cura Cura connect	180–280	140 max
Formlabs	Form 2	145 × 145 ×175 mm	25–100 mm	N/A	STL, OBJ	Formlabs	N/A	N/A

6. Summary and Conclusions

One of the material extrusion types in additive manufacturing systems, 3D printers are no longer only used in the industry for high-precision and strength parts manufacturing but are also widely used in both academics and industries for various applications. It is no longer rare to have a portable and small desktop 3D printer and manufacture your own designs in a few hours. 3D printers have continuously become smaller, faster, more efficient, handling more materials, and easier to customize and control than ever before. However, there is no guideline on how to select appropriate ones among various options for end-users, especially for the public in general and instructional subjects. Among many desktop 3D printers with various features, it is often challenging to select the best one for target applications and usages. In this paper, the authors introduce carefully selected, commercially available, consumer-reviewed, and major thermoplastic and photopolymer desktop 3D printers, and their representative models are compared with each other in their specifications and performance. This paper aims to provide beginner or advanced level end-users of desktop 3D printers with basic knowledge, selection criteria, an overview of 3D printing technologies for instructional applications, and their technical features, helping them to evaluate and select the appropriate 3D printers.

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