



The Printer Working Group

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Working Draft

IPP 3D Printing Extensions (3D)

Status: Interim

Abstract: This specification defines an extension to the Internet Printing Protocol and IPP Everywhere that supports printing of physical objects by Additive Manufacturing devices such as 3D printers.

This document is a PWG Working Draft. For a definition of a "PWG Working Draft", see:

<http://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

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2 Title: *IPP 3D Printing Extensions (3D)*

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176 **1. Introduction**

177 This white paper defines an extension to the Internet Printing Protocol (IPP) that supports
178 printing of physical objects by Additive Manufacturing devices such as three-dimensional
179 (3D) printers. The attributes and values defined in this document have been prototyped
180 using the CUPS software [CUPS].

181 The primary focus of this document is on popular Fused Deposition Modeling (FDM)
182 devices that melt and extrude ABS and/or PLA filaments in layers to produce a physical,
183 3D object. However, the same attributes can be used for other types of 3D printers that
184 use different methods and materials such as Laser Sintering of powdered materials and
185 curing of liquids using ultraviolet light.

186 This document also addresses common Cloud-based issues by extending the IPP Shared
187 Infrastructure Extensions [PWG5100.18], although how such services are provisioned or
188 managed is out of scope.

189 This document does not address the larger issue of choosing a common Object Definition
190 Language (ODL) for interoperability, however there are suggested MIME media type
191 names listed in section 13 for several formats in common use as well as strategies for
192 mapping material definitions in the Job Ticket to the ODL content.

193 **1.1 Previous Solutions**

194 3D printers are commonly bundled with so-called "slicer" software that converts ODL files
195 into a suitable low-level format (G-code, etc.) for the printer. The file produced by the slicer
196 software is then copied to a SD memory card and inserted in a slot on the printer where it
197 can be selected for printing. Some printers also support job submission via USB interface,
198 and third-party Cloud solutions often use the USB interface to print jobs received through
199 the Cloud.

200 Unfortunately, the USB serial protocol used for 3D printers does not support identification
201 of 3D printers or their capabilities, nor is there a single standard protocol in use during job
202 submission or processing (printing). This combined with the use of printer-specific file
203 formats makes direct printing infeasible outside the narrow range of computers supported
204 by the manufacturer, an issue that has plagued 2D printing for years and that the PWG
205 IPP workgroup has helped to mitigate through projects such as IPP Everywhere.

206

207 **2. Terminology**

208 **2.1 Conformance Terminology**

209 Capitalized terms, such as MUST, MUST NOT, RECOMMENDED, REQUIRED, SHOULD,
210 SHOULD NOT, MAY, and OPTIONAL, have special meaning relating to conformance as
211 defined in Key words for use in RFCs to Indicate Requirement Levels [RFC2119]. The
212 term CONDITIONALLY REQUIRED is additionally defined for a conformance requirement
213 that applies when a specified condition is true.

214 **2.2 Printing Terminology**

215 Normative definitions and semantics of printing terms are imported from IETF Printer MIB
216 v2 [RFC3805], IETF Finisher MIB [RFC3806], and IETF Internet Printing Protocol/1.1:
217 Model and Semantics [RFC2911].

218 *Document*: An object created and managed by a Printer that contains the description,
219 processing, and status information. A Document object may have attached data and is
220 bound to a single Job.

221 *Job*: An object created and managed by a Printer that contains description, processing,
222 and status information. The Job also contains zero or more Document objects.

223 *Logical Device*: a print server, software service, or gateway that processes jobs and either
224 forwards or stores the processed job or uses one or more Physical Devices to render
225 output.

226 *Output Device*: a single Logical or Physical Device

227 *Physical Device*: a hardware implementation of a endpoint device, e.g., a marking engine,
228 a fax modem, etc.

229 **2.3 Protocol Role Terminology**

230 This document also defines the following protocol roles in order to specify unambiguous
231 conformance requirements:

232 *Client*: Initiator of outgoing connections and sender of outgoing operation requests
233 (Hypertext Transfer Protocol -- HTTP/1.1 [RFC7230] User Agent).

234 *Printer*: Listener for incoming connections and receiver of incoming operation requests
235 (Hypertext Transfer Protocol -- HTTP/1.1 [RFC7230] Server) that represents one or more
236 Physical Devices or a Logical Device.

237 **2.4 3D Printing Terminology**

238 *Additive Manufacturing*: A 3D printing process where material is progressively added to
239 produce the final output.

240 *Binder Jetting*: A 3D printing process that uses a liquid binder that is jetted to fuse layers of
241 powdered materials.

242 *Digital Light Processing*: A 3D printing process that uses light with a negative image to
243 selectively cure layers of a liquid material.

244 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw
245 layers.

246 *Laser Sintering*: A 3D printing process that uses a laser to melt and fuse layers of
247 powdered materials.

248 *Material Jetting*: A 3D printing process that jets the actual build materials in liquid or molten
249 state to produce layers.

250 *Selective Deposition Lamination*: A 3D printing process that laminates cut sheets of
251 material.

252 *Stereo Lithography*: A 3D printing process that uses a laser to cure and fuse layers of
253 liquid materials.

254 *Subtractive Manufacturing*: A 3D printing process where material is progressively removed
255 to produce the final output.

256 **2.5 Acronyms and Organizations**

257 *CNC*: Computer Numerical Control

258 *DLP*: Digital Light Processing

259 *FDM*: Fused Deposition Modeling

260 *IANA*: Internet Assigned Numbers Authority, <http://www.iana.org/>

261 *IETF*: Internet Engineering Task Force, <http://www.ietf.org/>

262 *ISO*: International Organization for Standardization, <http://www.iso.org/>

263 *ODL*: Object Definition Language

264 *PWG*: Printer Working Group, <http://www.pwg.org/>

265 *SD*: SD Card Association, <http://www.sdcard.org/>

- 266 *SDL*: Selective Deposition Lamination
- 267 *SL*: Stereo Lithography
- 268 *USB*: Universal Serial Bus, <http://www.usb.org/>
- 269

270 **3. Rationale for IPP 3D Printing Extensions**

271 Existing specifications define the following:

- 272 1. IPP/2.0 Second Edition [PWG5100.12] defines version 2.0, 2.1, and 2.2 of the
273 Internet Printing Protocol which defines a standard operating and data model,
274 interface protocol, and extension mechanism to support traditional Printers;
- 275 2. IPP Everywhere [PWG5100.14] defines a profile of existing IPP specifications,
276 standard Job Template attributes, and standard document formats;
- 277 3. IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] defines an
278 interface for printing through shared services based in infrastructure such as
279 Cloud servers;
- 280 4. The 3D Manufacturing Format Core Specification & Reference Guide v1.0 [3MF]
281 defines an XML schema and file format for describing 3D objects with one or
282 more materials.

283 Therefore, this IPP 3D Printing Extensions (3D) document should define IPP attributes,
284 values, and operations needed to support printing of 3D objects, status monitoring of 3D
285 printers and print jobs, and configuration of 3D printer characteristics and capabilities.

286 **3.1 Use Cases**

287 **3.1.1 Print a 3D Object**

288 Jane is viewing a 3D object and wishes to print it. After initiating a print action, she selects
289 a 3D printer on the network, specifies material and print settings, and submits the object
290 for printing.

291 **3.1.2 Print a 3D Object Using Loaded Materials**

292 Jane is viewing a 3D object and wishes to print it. After initiating a print action, she selects
293 a 3D printer on the network that has the material(s) she wishes to use, specifies additional
294 print settings, and submits the object for printing.

295 **3.1.3 Print a 3D Object with Multiple Materials**

296 Jane wants to print a multi-material object on a single-material Printer. Jane uses software
297 on her Client device to create Document data that instructs the Printer to pause printing
298 and provide status information at specific layers so that she can change materials at the
299 Printer and resume printing with the new material.

300 **3.1.4 View a 3D Object During Printing**

301 Jane has submitted a 3D print Job that will take 4 hours to complete. She can visually
302 monitor the progress of the Job through a web page provided by the Printer.

303 **3.2 Exceptions**

304 **3.2.1 Clogged Extruder**

305 While printing a 3D object, the extruder becomes clogged. The printer stops printing and
306 sets the corresponding state reason to allow Jane's Client device to discover the issue and
307 display an appropriate alert.

308 **3.2.2 Extruder Temperature Out of Range**

309 While printing a 3D object, the extruder temperature goes out of range for the material
310 being printed. The printer pauses printing until the temperature stabilizes and sets the
311 corresponding state reason to allow Jane's Client device to discover the issue and display
312 an appropriate alert.

313 **3.2.3 Extruder Head Movement Issues**

314 While printing a 3D object, the extruder head movement becomes irregular. The Printer
315 stops printing and sets the corresponding state reason to allow Jane's Client device to
316 discover the issue and display an appropriate alert.

317 **3.2.4 Filament Feed Jam**

318 While printing a 3D object, the filament jams and cannot be fed into the extruder. The
319 printer stops printing and sets the corresponding state reason to allow Jane's Client device
320 to discover the issue and display an appropriate alert.

321 **3.2.5 Filament Feed Skip**

322 While printing a 3D object, the filament extrusion rate is insufficient to maintain proper
323 printing. The printer stops printing and sets the corresponding state reason to allow Jane's
324 Client device to discover the issue and display an appropriate alert.

325 **3.2.6 Material Empty**

326 While printing a 3D object, the printer runs out of the printing material. The printer pauses
327 printing until more material is loaded and sets the corresponding state reason to allow
328 Jane's Client device to discover the issue and display an appropriate alert.

329 **3.2.7 Material Adhesion Issues**

330 While printing a 3D object, the printed object releases from the build platform or the current
331 layer is not adhering to the previous one. The printer stops printing and sets the
332 corresponding state reason to allow Jane's Client device to discover the issue and display
333 an appropriate alert.

334 **3.2.8 Print Bed Temperature Out of Range**

335 While printing a 3D object, the print bed temperature goes out of the requested range. The
336 printer pauses printing until the temperature stabilizes and sets the corresponding state
337 reason to allow Jane's Client device to discover the issue and display an appropriate alert.

338 **3.2.9 Print Bed Not Clear**

339 When starting to print a 3D object, the Printer detects that the build platform is not
340 empty/clear. The Printer stops printing and sets the corresponding state reason to allow
341 Jane's Client device to discover the issue and display an appropriate alert. The Printer
342 starts printing once the build platform is cleared.

343 **3.3 Out of Scope**

344 The following are considered out of scope for this document:

- 345 1. Definition of new file formats; and
- 346 2. Support for Subtractive Manufacturing technologies such as CNC milling
- 347 machines.

348 **3.4 Design Requirements**

349 The design requirements for this document are:

- 350 1. Define attributes and values to describe supported and loaded (ready) materials
- 351 used for FDM; and
- 352 2. Define attributes and values to describe FDM printer capabilities and state

353 The design recommendations for this document are:

- 354 1. Support 3D printing technologies other than FDM

355

356 **4. 3D Print Service Model**

357 The IPP/1.1 Model and Semantics [RFC2911], the IETF Printer MIB [RFC3805], and the
358 IETF Finisher MIB [RFC3806] already define a comprehensive model for the operation and
359 data elements of a typical 2D printer. Figure 1 shows the generalized IPP model. The IPP
360 Server provides the external network interface for IPP Clients, while the Print Service
361 manages and processes Jobs and communicates with the Output Device(s) and their sub-
362 units.

363 IPP objects in the model include Printers, Jobs, Documents, and Subscriptions. Each
364 object has associated named attributes, each with one or more strongly typed values.
365 Status attributes are immutable (READ-ONLY) while Description and Template attributes
366 can be mutable (READ-WRITE). Objects can be the target of IPP operations, for example
367 the Printer object accepts the Create-Job operation to create new Job objects for that
368 Printer.

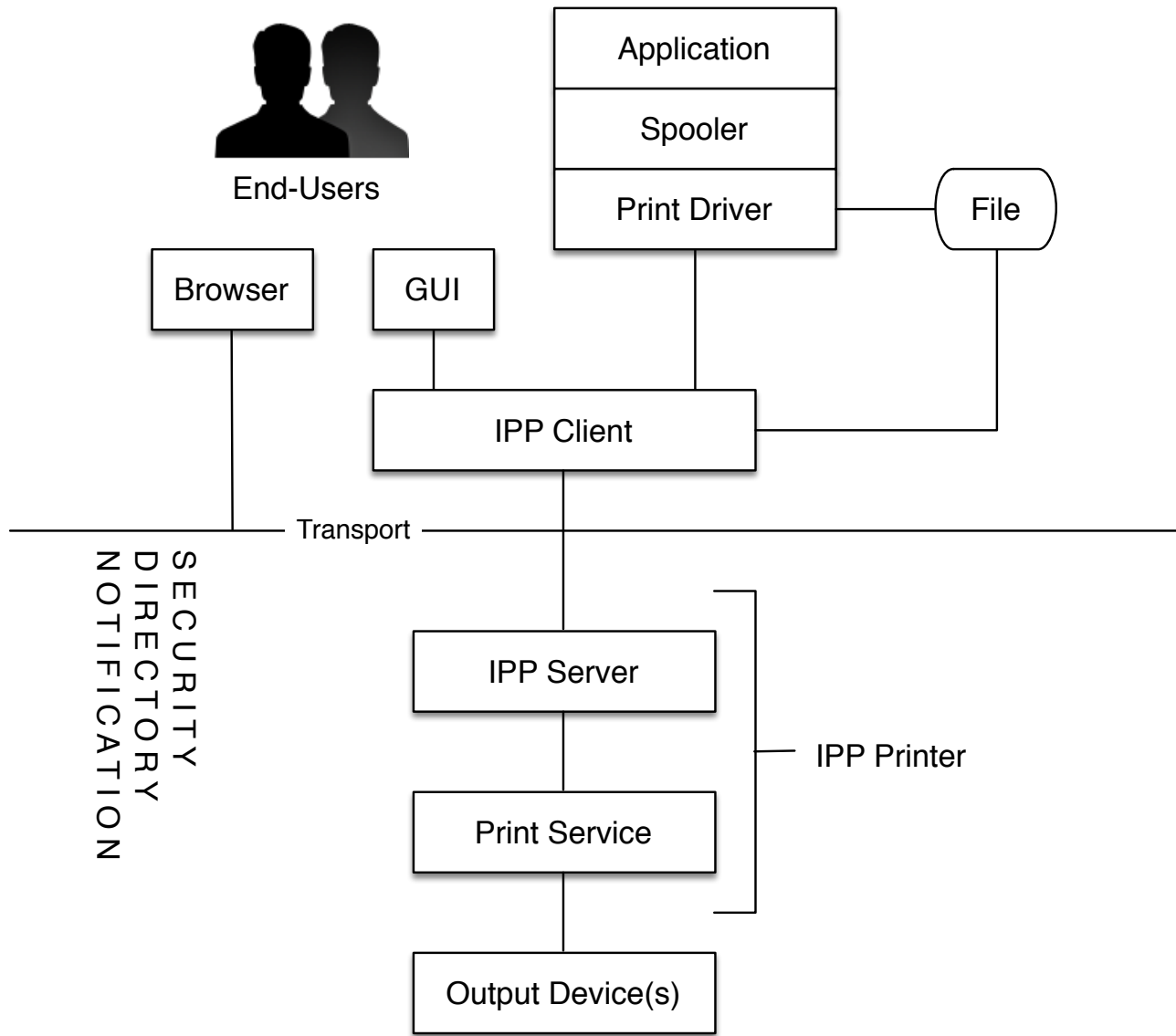
369 The IPP Printer object contains zero or more Job objects and is responsible for managing,
370 scheduling, and processing Jobs. It also provides the current state of the Output Device(s)
371 and communicates with them as needed.

372 The IPP Job object contains zero or more Document objects and tracks the progress of the
373 Job throughout its life cycle. The Job Ticket (attributes supplied when creating the Job)
374 and Job Receipt (attributes describing the final disposition of the Job) are also stored here.

375 The IPP Document object contains the document data or a reference (URI) to the data and
376 tracks the progress of the Document throughout its life cycle. The Document Ticket
377 (attributed supplied when creating the Document) and Document Receipt (attributes
378 describing the final disposition of the Document) are also stored here.

379 The IPP Subscription object contains event notifications for one or more conditions that are
380 being monitored. The Subscription Ticket (attribute supplied when creating the
381 Subscription) is also stored here and determines whether notifications are pushed (email,
382 instant messaging, etc.) or pulled (Get-Notifications operation).

383



384

385

386

Figure 1 - Generalized IPP Model (RFC 2911)

387 4.1 3D Print Service

388 3D printing uses a variation of the traditional Print service that maintains state and
 389 capability information specific to 3D printing. The 3D Print service supports all of the same
 390 operations of the Print service described in [RFC2911] except for the Print-Job and Print-
 391 URI operations which are compound operations that are not used in newer IPP services.
 392 Similarly, the 3D Print service uses a superset of the Print service attributes except where
 393 such attributes are not applicable, for example the "media" attributes for a 3D printer that
 394 does not use media sheets. Attributes specific to the 3D Print Service are defined in
 395 section 5.

396

397

398

399 4.2 3D Printer Subunits

400 Table 1 lists the subunits of 3D printers for different technologies.

401

Table 1 - 3D Printer Subunits

Subunit	Technology	Reference
Cutters	SDL	RFC 3806
Doors	All	RFC 3805
Input Trays	SDL	RFC 3805
Marker Supplies	All	RFC 3805
Markers (or Extruders)	Many	RFC 3805
Media Path	SDL	RFC 3805
Build Platforms	All	Section 4.2.1
Cameras	All	Section 4.2.2
Chamber	All	Section 4.2.3
Fans	FDM	Section 4.2.5
Lamps	DLP	Section 4.2.6
Lasers	Laser Sintering, SL	Section 4.2.7
Motors	All	Section 4.2.9
Reservoirs	DLP, Laser Sintering, SL	Section 4.2.10

402 4.2.1 Build Platforms

403 Build Platforms hold the printed object. The platform typically moves up or down during
 404 printing as layers are applied, although in some cases it moves along all three axis.

405 4.2.2 Cameras

406 Cameras typically show the Build Platforms, offering a visual progress/status reporting for
 407 remote users.

408 4.2.3 Chambers

409 Chambers are the volumes containing the objects being printed. Chambers are sometimes
410 temperature controlled and/or have doors that provide access to the printed objects.

411 4.2.4 Cutters

412 Cutters are used to trim support material on printed objects and/or remove regions of
413 media that are not part of the final printed object.

414 4.2.5 Fans

415 Fans are used to cool printed material and maintain proper extruder and material
416 temperatures.

417 4.2.6 Lamps

418 Lamps are used by DLP printers to provide an ultraviolet light source for curing the liquid
419 material while printing a layer. Lamps are also used to illuminate the Build Platforms.

420 4.2.7 Lasers

421 Lasers are used by Laser Sintering and Stereo Lithography (SL) printers to fuse powdered
422 material or cure liquid material while printing a layer.

423 4.2.8 Markers (or Extruders)

424 Markers can be traditional subunits where an image is printed on sheets of paper (SDL),
425 extruders that place material onto the Build Platform or previous layer, or projectors that
426 display an inverse image on the surface of a liquid material (DLP).

427 4.2.9 Motors

428 Motors are used to move the Build Platforms and (in some cases) move the Markers.

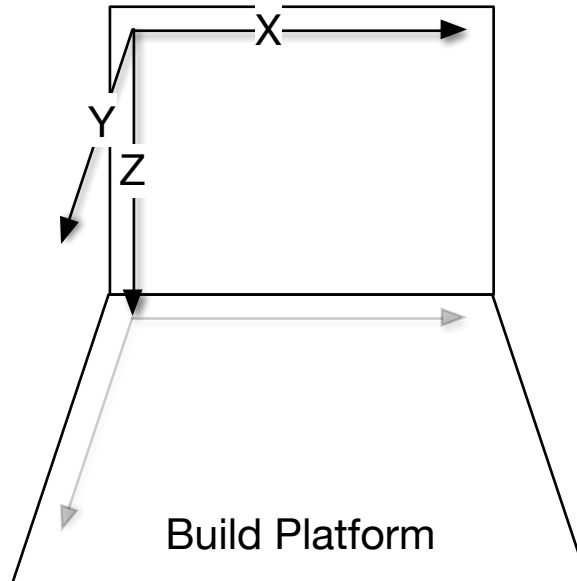
429 4.2.10 Reservoirs

430 Reservoirs hold liquid or powdered material used to create the printed object.

431 4.3 3D Printer Coordinate System

432 3D printers operate in three dimensions and thus have three axis of movement. Figure 2
433 shows a typical coordinate system where the X axis represents the width of the object, the
434 Y axis represents the depth of the object, and the Z axis represents the height of the
435 object. Note that, depending on the technology used, the Z axis may move in the opposite
436 direction, or the extruder may move independently with a stationary build platform.

437



438

439

Figure 2 - Typical Build Platform Coordinate System

440 Filament usage by extrusion Printers is sometimes also modeled as an additional "E" axis,
441 e.g., E1 for the first filament, E2 for the second filament, etc.

442 The Printer's coordinate system is often different than the coordinate system used in the
443 ODL file to describe the object(s) being printed. The ODL interpreter on the Printer is
444 responsible for performing any transformations needed to prepare the geometry for slicing
445 in the Printer's coordinate system.

446 **4.4 Output Intent and Job Processing**

447 As with 2D printing, the focus of 3D printing using IPP is specification of output intent and
448 not for process or device control. Clients can specify general material selections ("red
449 PLA", "brown wood PLA", "clear ABS", etc.), print speed and quality, build platform and
450 chamber temperatures, and whether supports and rafts should be printed. Printers then
451 use the implementation specific device control and (ordered) processes to satisfy the
452 Client-supplied output intent when processing the Job.

453 Also as with 2D printing, 3D Printers process Jobs using one or more interpreters. 2D
454 printing typically involves rasterization of the document data while 3D printing involves
455 geometric transformations, addition of support geometry, and slicing (laying) of the
456 object(s) in the document data so that they can be printed.

457 **4.5 Job Spooling**

458 Because common ODL formats are not designed to be incrementally processed as a
459 stream of data, 3D printers will likely only support spooled (stored) processing of Jobs and
460 Documents.

461 4.6 Cloud-Based Printing

462 Cloud-based printing is supported by the existing IPP Shared Infrastructure Extensions
463 (INFRA) [PWG5100.18]. Infrastructure Printers might require additional configuration or
464 selection of drivers for the printer being configured, however that is outside the scope of
465 this specification and can be considered a part of provisioning the Cloud Service.

466 Snapshots of camera video are uploaded as JPEG image resources using HTTP PUT
467 requests from the Proxy to the Infrastructure Printer. Such resources **MUST** be updated in
468 an atomic fashion to allow Clients to safely poll for updates to the camera video.
469

470 **5. New Attributes**471 **5.1 Job Template Attributes**

472 Table 2 lists the Job Template attributes and their corresponding “-default” and “-
473 supported” attributes.

474 **Table 2 - Job Template Attributes**

Job Template	Printer: Default	Printer: Supported
materials-col (collection)	materials-col-default (1setOf collection)	materials-col-database (1setOf collection) materials-col-ready (1setOf collection) materials-col-supported (1setOf type2 keyword)
print-fill-density (integer(0:100))	print-fill-density-default (integer(0:100))	<none>
print-fill-thickness (integer(0:MAX))	print-fill-thickness-default (integer(0:MAX))	print-fill-thickness-supported (1setOf (integer(0:MAX) rangeOfInteger(0:MAX)))
print-layer-thickness (integer(0:MAX))	print-layer-thickness-default (integer(0:MAX))	print-layer-thickness-supported (1setOf (integer(0:MAX) rangeOfInteger(0:MAX)))
print-rafts (type2 keyword)	print-rafts-default (type2 keyword)	print-rafts-supported (1setOf type2 keyword)
print-shell-thickness (integer(0:MAX))	print-shell-thickness-default (integer(0:MAX))	print-shell-thickness-supported (1setOf (integer(0:MAX) rangeOfInteger(0:MAX)))
print-speed (integer(1:MAX))	print-speed-default (integer(1:MAX))	print-speed-supported (1setOf (integer(1:MAX) rangeOfInteger(1:MAX)))
print-supports (type2 keyword)	print-supports-default (type2 keyword)	print-supports-supported (1setOf type2 keyword)
printer-bed-temperature (integer no-value)	printer-bed-temperature-default (integer no-value)	printer-bed-temperature-supported (1setOf (integer rangeOfInteger) no-value)
printer-chamber-temperature (integer no-value)	printer-chamber-temperature-default (integer no-value)	printer-chamber-temperature-supported (1setOf (integer rangeOfInteger) no-value)
printer-fan-speed (integer(0:100))	printer-fan-speed-default (integer(0:100))	printer-fan-speed-supported (boolean)

475 **5.1.1 materials-col (1setOf collection)**

476 This Job Template attribute defines the materials to be used for the Job. When specified,
 477 the Printer validates the requested materials both when the Job is created and when it
 478 enters the 'processing' state. If the requested materials are not loaded, the 'material-
 479 needed' keyword is added to the Printer's "printer-state-reasons" values and the Job is
 480 placed in the 'processing-stopped' state.

481 The Client typically supplies "materials-col" values matching those returned in the
 482 "materials-col-database" (section 5.3.1) or "materials-col-ready" (section 5.3.10) Printer
 483 Description attributes. Table 3 lists the member attributes.

484 **Table 3 - "materials-col" Member Attributes**

Member Attribute	Printer: Supported Values
material-amount	N/A
material-amount-units	material-amount-units-supported
material-color	N/A
material-diameter	material-diameter-supported
material-key	materials-col-database materials-col-ready
material-name	materials-col-database materials-col-ready
material-purpose	material-purpose-supported
material-rate	material-rate-supported
material-rate-units	material-rate-units-supported
material-temperate	material-temperature-supported
material-type	material-type-supported

485 **5.1.1.1 material-amount (integer(0:MAX) | unknown)**

486 This member attribute provides the estimated amount of material that is available
 487 ("materials-col-database" and "materials-col-ready" values), the estimated amount of
 488 material that is required ("materials-col" values), or the actual amount of material that has
 489 been used ("materials-col-actual" values).

490 **5.1.1.2 material-amount-units (type2 keyword)**

491 This member attribute provides the units for the "material-amount" value. Values include:

492 'g': Value is mass in grams.

493 'kg': Value is mass in kilograms.

494 'l': Value is volume in liters.

495 'm': Value is length in meters.

496 'ml': Value is volume in milliliters.

497 'mm': Value is length in millimeters.

498 **5.1.1.3 material-color (type2 keyword)**

499 This member attribute provides a PWG media color [PWG5101.1] value representing the
500 color of the material.

501 **5.1.1.4 material-diameter (integer(1:MAX))**

502 This member attribute provides the diameter of the filament in nanometers and is only
503 used for filament materials.

504 **5.1.1.5 material-key (keyword)**

505 This member attribute provides an unlocalized name of the material that can be localized
506 using the strings file referenced by the "printer-strings-uri" Printer attribute.

507 **5.1.1.6 material-name (name(MAX))**

508 This member attribute provides a localized name of the material.

509 **5.1.1.7 material-purpose (1setOf type2 keyword)**

510 This member attribute specifies what the material will be used for. Values include:

511 'all': The material will be used for all parts of the printed object.

512 'in-fill': The material will be used to fill the interior of the printed object.

513 'raft': The material will be used to print a raft under the printed object.

514 'shell': The material will be used for the surface of the printed object.

515 'support': The material will be used to support the printed object.

516 **5.1.1.8 material-rate (integer(1:MAX))**

517 This member attribute provides the flow rate of the material per second. The units are
518 defined by the "material-rate-units" member attribute.

519 **5.1.1.9 material-rate-units (type2 keyword)**

520 This member attribute provides the units for the "material-rate" member attribute. Values
521 include:

522 'mg': Value is milligrams per second.

523 'ml': Value is milliliters per second.

524 'mm': Value is millimeters per second.

525 **5.1.1.10 material-temperature (integer(-273:MAX) | rangeOfInteger(-273:MAX))**

526 This member attribute specifies the temperature (or range of temperatures) for the material
527 in degrees Celsius.

528 **5.1.1.11 material-type (type2 keyword)**

529 This member attribute specifies the type of material. The keyword consists of a material
530 name ('abs', 'pla', 'pla-flexible', etc.) and form ('filament', 'liquid', 'powder', etc.) separated
531 by an underscore. Material names and forms cannot contain the underscore (_) character,
532 which is reserved as a separator in the keyword value. Values include:

533 'abs_filament': Acrylonitrile Butadiene Styrene (ABS) filament.

534 'abs-carbon-fiber_filament': ABS filament reinforced with carbon fibers.

535 'abs-carbon-nanotube_filament': ABS filament reinforced with carbon nanotubes.

536 'chocolate_powder': Chocolate powder.

537 'gold_powder': Gold (metal) powder.

538 'nylon_filament': Nylon filament.

539 'pet_filament': Polyethylene terephthalate (PET) filament.

540 'photopolymer-resin_liquid': Photopolymer (liquid) resin.

541 'pla_filament': Polylactic Acid (PLA) filament.

542 'pla-conductive_filament': Conductive PLA filament.

543 'pla-dissolvable_filament': Dissolvable PLA filament.

544 'pla-flexible_filament': Flexible PLA filament.

545 'pla-magnetic_filament': PLA with embedded iron particles.

546 'pla-steel-filament': PLA with embedded steel particles.

547 'pla-stone_filament': PLA filament with embedded stone chips.

548 'pla-wood_filament': PLA filament with embedded wood fibers.

549 'polycarbonate_filament': Polycarbonate filament.

550 'silver_powder': Silver (metal) powder.

551 'titanium_powder': Titanium (metal) powder.

552 'wax_solid': Solid wax.

553 **5.1.2 print-fill-density (integer(0:100))**

554 This Job Template attribute specifies the in-fill density of interior regions in percent.

555 **5.1.3 print-fill-thickness (integer(0:MAX))**

556 This Job Template attribute specifies the thickness of any in-fill walls in nanometers, with 0
557 representing the thinnest possible walls.

558 **5.1.4 print-layer-thickness (integer(0:MAX))**

559 This Job Template attribute specifies the thickness of each layer in nanometers, with 0
560 representing the thinnest possible layers.

561 **5.1.5 print-rafts (type2 keyword)**

562 This Job Template attribute specifies whether to print brims, rafts, or skirts under the
563 object. Values include:

564 'none': Do not print brims, rafts, or skirts.

565 'brim': Print brims using the 'raft' material specified for the Job.

566 'raft': Print rafts using the 'raft' material specified for the Job.

567 'skirt': Print skirts using the 'raft' material specified for the Job.

568 'standard': Print brims, rafts, and/or skirts using implementation-defined default
569 parameters.

570 **5.1.6 print-shell-thickness (integer(0:MAX))**

571 This Job Template attribute specifies the thickness of exterior walls in nanometers, with 0
572 representing the thinnest possible wall.

573 **5.1.7 print-speed (integer(1:MAX))**

574 This Job Template attribute specifies the printing speed in nanometers per second.

575 **5.1.8 print-supports (type2 keyword)**

576 This Job Template attribute specifies whether to print supports under the object. Values
577 include:

578 'none': Do not print supports.

579 'standard': Print supports using implementation-defined default parameters.

580 'material': Print supports using the 'support' material specified for the Job.

581 **5.1.9 printer-chamber-temperature (integer(-273:MAX) | no-value)**

582 This Job Template attribute specifies the desired print chamber temperature in degrees
583 Celsius. The 'no-value' value is used to disable temperature control in the print chamber.

584 **5.1.10 printer-fan-speed (integer(0:100))**

585 This Job Template attribute specifies the desired fan speed in percent of maximum. A
586 value of 0 turns the fans off during printing.

587 **5.1.11 printer-platform-temperature (integer(-273:MAX) | no-value)**

588 This Job Template attribute specifies the desired Build Platform temperature in degrees
589 Celsius. The 'no-value' value is used to disable temperature control on the Build Platform.

590 **5.2 Job Description Attributes**

591 **5.2.1 materials-col-actual (1setOf collection)**

592 This Job Description attribute provides a receipt of the actual material(s) used for the Job.

593 **5.3 Printer Description Attributes**

594 **5.3.1 material-amount-units-supported (1setOf type2 keyword)**

595 This Printer Description attribute lists the supported "material-amount-units" values for the
596 Printer.

597 **5.3.2 material-diameter-supported (1setOf (integer | rangeOfInteger))**

598 This Printer Description attribute lists the supported "material-diameter" values for the
599 Printer.

600 **5.3.3 material-purpose-supported (1setOf type2 keyword)**

601 This Printer Description attribute lists the supported "material-purpose" values for the
602 Printer.

603 **5.3.4 material-rate-supported (1setOf (integer | rangeOfInteger))**

604 This Printer Description attribute lists the supported "material-rate" values for the Printer.

605 5.3.5 material-rate-units-supported (1setOf type2 keyword)

606 This Printer Description attribute lists the supported "material-rate-units" values for the
607 Printer.

**608 5.3.6 material-temperature-supported (1setOf (integer(-273:MAX) | rangeOfInteger(-
609 273:MAX)))**

610 This Printer Description attribute specifies the supported "material-temperature" values (or
611 ranges of values) in degrees Celsius.

612 5.3.7 material-type-supported (1setOf type2 keyword)

613 This Printer Description attribute lists the supported "material-type" values for the Printer.

614 5.3.8 materials-col-database (1setOf collection)

615 This Printer Description attribute lists the pre-configured materials for the Printer. Each
616 value contains the corresponding "materials-col" member attributes and will typically reflect
617 vendor and site ("third party") materials that are supported by the Printer.

618 5.3.9 materials-col-default (1setOf collection)

619 This Printer Description attribute lists the default materials that will be used if the
620 "materials-col" Job Template attribute is not specified.

621 5.3.10 materials-col-ready (1setOf collection)

622 This Printer Description attribute lists the materials that have been loaded into the Printer.
623 Each value contains the corresponding "materials-col" member attributes.

624 5.3.11 materials-col-supported (1setOf type2 keyword)

625 This Printer Description attribute lists the "materials-col" member attributes that are
626 supported by the Printer.

627 5.3.12 print-fill-density-default (integer(0:100))

628 This Printer Description attribute specifies the default "print-fill-density" value in percent.

629 5.3.13 print-fill-thickness-default (integer(0:MAX))

630 This Printer Description attribute specifies the default "print-fill-thickness" value in
631 nanometers.

632 **5.3.14 print-fill-thickness-supported (1setOf (integer(0:MAX) |**
633 **rangeOfInteger(0:MAX)))**

634 This Printer Description attribute lists the supported "print-fill-thickness" values (or ranges
635 of values) in nanometers.

636 **5.3.15 print-layer-order (type1 keyword)**

637 This Printer Description attribute specifies the order of layers when printing, either 'top-to-
638 bottom' or 'bottom-to-top'.

639 **5.3.16 print-layer-thickness-default (integer(0:MAX))**

640 This Printer Description attribute specifies the default "print-layer-thickness" value in
641 nanometers.

642 **5.3.17 print-layer-thickness-supported (1setOf (integer(0:MAX) |**
643 **rangeOfInteger(0:MAX)))**

644 This Printer Description attribute lists the supported values (or ranges of values) for the
645 "print-layer-thickness" Job Template attribute.

646 **5.3.18 print-rafts-default (type2 keyword)**

647 This Printer Description attribute specifies the default "print-rafts" value.

648 **5.3.19 print-rafts-supported (1setOf type2 keyword)**

649 This Printer Description attribute lists the supported "print-rafts" values.

650 **5.3.20 print-shell-thickness-default (integer(0:MAX))**

651 This Printer Description attribute specifies the default "print-shell-thickness" value in
652 nanometers.

653 **5.3.21 print-shell-thickness-supported (1setOf (integer(0:MAX) |**
654 **rangeOfInteger(0:MAX)))**

655 This Printer Description attribute lists the supported "print-shell-thickness" values (or
656 ranges of values) in nanometers.

657 **5.3.22 print-speed-default (integer(1:MAX))**

658 This Printer Description attribute lists the default "print-speed" value in nanometers per
659 second.

660 **5.3.23 print-speed-supported (1setOf (integer(1:MAX) | rangeOfInteger(1:MAX)))**

661 This Printer Description attribute lists the supported "print-speed" values (or ranges of
662 values) in nanometers per second.

663 **5.3.24 print-supports-default (type2 keyword)**

664 This Printer Description attribute specifies the default "print-supports" value.

665 **5.3.25 print-supports-supported (1setOf type2 keyword)**

666 This Printer Description attribute lists the supported "print-supports" values.

667 **5.3.26 printer-accuracy-supported (collection)**

668 This Printer Description attribute specifies the absolute accuracy of the Printer. The "x-
669 accuracy (integer(1:MAX))", "y-accuracy (integer(1:MAX))", and "z-accuracy
670 (integer(1:MAX))" member attributes specify the accuracy in nanometers along each axis.

671 **5.3.27 printer-camera-image-uri (1setOf uri)**

672 This Printer Description attribute lists the URIs for one or more resident camera snapshots.
673 Each URI corresponds to a separate resident camera. The images referenced by each
674 URI can change at any time so it is up to the Client to periodically poll for changes and for
675 the Printer to atomically update the images so that Clients can safely do so.

676 **5.3.28 printer-chamber-temperature-default (integer(-273:MAX) | no-value)**

677 This Printer Description attribute specifies the default "printer-chamber-temperature" value
678 in degrees Celsius.

679 **5.3.29 printer-chamber-temperature-supported (1setOf (integer(-273:MAX) |
680 rangeOfInteger(-273:MAX)) | no-value)**

681 This Printer Description attribute lists the supported "printer-chamber-temperature" values
682 (or ranges of values) in degrees Celsius. The out-of-band 'no-value' value specifies that
683 the Printer does not offer temperature control of the print chamber.

684 **5.3.30 printer-fan-speed-default (integer(0:MAX))**

685 This Printer Description attribute specifies the default "printer-fan-speed" value in percent.

686 **5.3.31 printer-fan-speed-supported (boolean)**

687 This Printer Description attribute specifies whether the "printer-fan-speed" Job Template
688 attribute is supported.

689 5.3.32 printer-platform-temperature-default (integer(-273:MAX) | no-value)

690 This Printer Description attribute specifies the default "printer-platform-temperature" value
691 in degrees Celsius.

**692 5.3.33 printer-platform-temperature-supported (1setOf (integer(-273:MAX) |
693 rangeOfInteger(-273:MAX)) | no-value)**

694 This Printer Description attribute lists the supported "printer-platform-temperature" values
695 (or ranges of values) in degrees Celsius. The out-of-band 'no-value' value specifies that
696 the Printer does not offer temperature control of the Build Platform.

697 5.3.34 printer-volume-supported (collection)

698 This Printer Description attribute specifies the maximum build volume supported by the
699 Printer. The "x-dimension (integer(1:MAX))", "y-dimension (integer(1:MAX))", and "z-
700 dimension (integer(1:MAX))" member attributes specify the size in millimeters along each
701 axis.

702 5.4 Printer Status Attributes**703 5.4.1 printer-camera (1setOf collection)**

704 This Printer Status attribute provides current information about the camera sub-units, if
705 any, of the Printer. Each of the member attributes are modeled using the common Printer
706 MIB v2 [RFC3805] sub-unit properties.

707 5.4.1.1 camera-info (text(127))

708 This REQUIRED member attribute provides a localized description of the camera sub-unit.

709 5.4.1.2 camera-info-uri (uri)

710 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
711 providing additional information about the camera sub-unit.

712 5.4.1.3 camera-name (name(127))

713 This REQUIRED member attribute provides a unique name for the camera sub-unit.

714 5.4.1.4 camera-state (type1 enum)

715 This REQUIRED member attribute provides the overall state of the camera sub-unit.
716 Values are:

717 '3' ('idle'): The camera sub-unit is available and either idle or in standby mode.

718 '4' ('processing'): The camera sub-unit is available and either active or busy.

719 '5' ('stopped'): The camera sub-unit is unavailable.

720 **5.4.1.5 camera-state-reasons (1setOf type2 keyword)**

721 This CONDITIONALLY REQUIRED member attribute provides details concerning the
722 camera sub-unit state. Printers with more than one camera sub-unit MUST support this
723 member attribute. Values include:

724 'camera-failure': The camera is no longer working.

725 **5.4.2 printer-chamber (1setOf collection)**

726 This Printer Status attribute provides current information about the chamber sub-units, if
727 any, of the Printer. Each of the member attributes are modeled using the common Printer
728 MIB v2 [RFC3805] sub-unit properties.

729 **5.4.2.1 chamber-info (text(127))**

730 This REQUIRED member attribute provides a localized description of the chamber sub-
731 unit.

732 **5.4.2.2 chamber-info-uri (uri)**

733 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
734 providing additional information about the chamber sub-unit.

735 **5.4.2.3 chamber-name (name(127))**

736 This REQUIRED member attribute provides a unique name for the chamber sub-unit.

737 **5.4.2.4 chamber-state (type1 enum)**

738 This REQUIRED member attribute provides the overall state of the chamber sub-unit.
739 Values are:

740 '3' ('idle'): The chamber sub-unit is available and either idle or in standby mode.

741 '4' ('processing'): The chamber sub-unit is available and either active or busy.

742 '5' ('stopped'): The chamber sub-unit is unavailable.

743 **5.4.2.5 chamber-state-reasons (1setOf type2 keyword)**

744 This CONDITIONALLY REQUIRED member attribute provides details concerning the
745 chamber sub-unit state. Printers with more than one chamber sub-unit MUST support this
746 member attribute. Values include:

747 'chamber-cooling': A chamber is being cooled.

748 'chamber-heating': The chamber is being heated.

749 'chamber-temperature-high': The temperature of the chamber is high.

750 'chamber-temperature-low': The temperature of the chamber is low.

751 **5.4.2.6 chamber-temperature (integer(-273:MAX) | no-value)**

752 This REQUIRED member attribute provides the current print chamber temperature in
753 degrees Celsius. If the print chamber is not temperature controlled, the 'no-value' value is
754 returned.

755 **5.4.3 printer-cutter (1setOf collection)**

756 This Printer Status attribute provides current information about the cutter sub-units, if any,
757 of the Printer. Each of the member attributes are modeled using the common Printer MIB
758 v2 [RFC3805] sub-unit properties.

759 **5.4.3.1 cutter-info (text(127))**

760 This REQUIRED member attribute provides a localized description of the cutter sub-unit.

761 **5.4.3.2 cutter-info-uri (uri)**

762 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
763 providing additional information about the cutter sub-unit.

764 **5.4.3.3 cutter-name (name(127))**

765 This REQUIRED member attribute provides a unique name for the cutter sub-unit.

766 **5.4.3.4 cutter-state (type1 enum)**

767 This REQUIRED member attribute provides the overall state of the cutter sub-unit. Values
768 are:

769 '3' ('idle'): The cutter sub-unit is available and either idle or in standby mode.

770 '4' ('processing'): The cutter sub-unit is available and either active or busy.

771 '5' ('stopped'): The cutter sub-unit is unavailable.

772 **5.4.3.5 cutter-state-reasons (1setOf type2 keyword)**

773 This CONDITIONALLY REQUIRED member attribute provides details concerning the
774 cutter sub-unit state. Printers with more than one cutter sub-unit MUST support this
775 member attribute. Values include:

776 'cutter-at-eol': The cutter has reached its end-of-life and will need to be replaced
777 soon.

778 'cutter-failure': The cutter has failed.

779 'cutter-near-eol': The cutter is near its end-of-life and may need to be replaced soon.

780 **5.4.4 printer-extruder (1setOf collection)**

781 This Printer Status attribute provides current information about the extruder sub-units, if
782 any, of the Printer. Each of the member attributes are modeled using the common Printer
783 MIB v2 [RFC3805] sub-unit properties.

784 **5.4.4.1 extruder-info (text(127))**

785 This REQUIRED member attribute provides a localized description of the extruder sub-
786 unit.

787 **5.4.4.2 extruder-info-uri (uri)**

788 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
789 providing additional information about the extruder sub-unit.

790 **5.4.4.3 extruder-name (name(127))**

791 This REQUIRED member attribute provides a unique name for the extruder sub-unit.

792 **5.4.4.4 extruder-state (type1 enum)**

793 This REQUIRED member attribute provides the overall state of the extruder sub-unit.
794 Values are:

795 '3' ('idle'): The extruder sub-unit is available and either idle or in standby mode.

796 '4' ('processing'): The extruder sub-unit is available and either active or busy.

797 '5' ('stopped'): The extruder sub-unit is unavailable.

798 **5.4.4.5 extruder-state-reasons (1setOf type2 keyword)**

799 This CONDITIONALLY REQUIRED member attribute provides details concerning the
800 extruder sub-unit state. Printers with more than one extruder sub-unit MUST support this
801 member attribute. Values include:

802 'extruder-cooling': The extruder is being cooled.

803 'extruder-failure': The extruder has failed and requires maintenance or replacement.

804 'extruder-heating': The extruder is being heated.

805 'extruder-jam': The extruder is jammed or clogged.

806 'extruder-temperature-high': The temperature of the extruder is too high.

807 'extruder-temperature-low': The temperature of the extruder is too low.

808 **5.4.4.6 extruder-temperature (integer(-273:MAX) | no-value)**

809 This REQUIRED member attribute provides the current extruder head temperature in
810 degrees Celsius. The 'no-value' value is returned when the extruder head is not
811 temperature controlled.

812 **5.4.5 printer-fan (1setOf collection)**

813 This Printer Status attribute provides current information about the fan sub-units, if any, of
814 the Printer. Each of the member attributes are modeled using the common Printer MIB v2
815 [RFC3805] sub-unit properties.

816 **5.4.5.1 fan-info (text(127))**

817 This REQUIRED member attribute provides a localized description of the fan sub-unit.

818 **5.4.5.2 fan-info-uri (uri)**

819 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
820 providing additional information about the fan sub-unit.

821 **5.4.5.3 fan-name (name(127))**

822 This REQUIRED member attribute provides a unique name for the fan sub-unit.

823 **5.4.6 fan-speed (integer(0:100))**

824 This REQUIRED member attribute provides the current fan speed in percent.

825 **5.4.6.1 fan-state (type1 enum)**

826 This REQUIRED member attribute provides the overall state of the fan sub-unit. Values
827 are:

828 '3' ('idle'): The fan sub-unit is available and either idle or in standby mode.

829 '4' ('processing'): The fan sub-unit is available and either active or busy.

830 '5' ('stopped'): The fan sub-unit is unavailable.

831 5.4.6.2 fan-state-reasons (1setOf type2 keyword)

832 This CONDITIONALLY REQUIRED member attribute provides details concerning the fan
833 sub-unit state. Printers with more than one fan sub-unit MUST support this member
834 attribute. Values include:

835 'fan-failure': The fan has failed.

836 5.4.7 printer-lamp (1setOf collection)

837 This Printer Status attribute provides current information about the lamp sub-units, if any,
838 of the Printer. Each of the member attributes are modeled using the common Printer MIB
839 v2 [RFC3805] sub-unit properties.

840 5.4.7.1 lamp-info (text(127))

841 This REQUIRED member attribute provides a localized description of the lamp sub-unit.

842 5.4.7.2 lamp-info-uri (uri)

843 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
844 providing additional information about the lamp sub-unit.

845 5.4.7.3 lamp-name (name(127))

846 This REQUIRED member attribute provides a unique name for the lamp sub-unit.

847 5.4.7.4 lamp-state (type1 enum)

848 This REQUIRED member attribute provides the overall state of the lamp sub-unit. Values
849 are:

850 '3' ('idle'): The lamp sub-unit is available and either idle or in standby mode.

851 '4' ('processing'): The lamp sub-unit is available and either active or busy.

852 '5' ('stopped'): The lamp sub-unit is unavailable.

853 5.4.7.5 lamp-state-reasons (1setOf type2 keyword)

854 This CONDITIONALLY REQUIRED member attribute provides details concerning the lamp
855 sub-unit state. Printers with more than one fan sub-unit MUST support this member
856 attribute. Values include:

857 'lamp-at-eol': The lamp has reached its end-of-life and will need to be replaced
858 soon.

859 'lamp-failure': The lamp has failed.

860 'lamp-near-eol': The lamp is near its end-of-life and may need to be replaced soon.

861 **5.4.8 printer-laser (1setOf collection)**

862 This Printer Status attribute provides current information about the laser sub-units, if any,
863 of the Printer. Each of the member attributes are modeled using the common Printer MIB
864 v2 [RFC3805] sub-unit properties.

865 **5.4.8.1 laser-info (text(127))**

866 This REQUIRED member attribute provides a localized description of the laser sub-unit.

867 **5.4.8.2 laser-info-uri (uri)**

868 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
869 providing additional information about the laser sub-unit.

870 **5.4.8.3 laser-name (name(127))**

871 This REQUIRED member attribute provides a unique name for the laser sub-unit.

872 **5.4.8.4 laser-state (type1 enum)**

873 This REQUIRED member attribute provides the overall state of the laser sub-unit. Values
874 are:

875 '3' ('idle'): The laser sub-unit is available and either idle or in standby mode.

876 '4' ('processing'): The laser sub-unit is available and either active or busy.

877 '5' ('stopped'): The laser sub-unit is unavailable.

878 **5.4.8.5 laser-state-reasons (1setOf type2 keyword)**

879 This CONDITIONALLY REQUIRED member attribute provides details concerning the laser
880 sub-unit state. Printers with more than one fan sub-unit MUST support this member
881 attribute. Values include:

882 'laser-at-eol': The laser has reached its end-of-life and will need to be replaced
883 soon.

884 'laser-failure': The laser has failed.

885 'laser-near-eol': The laser is near its end-of-life and may need to be replaced soon.

886 5.4.9 printer-motor (1setOf collection)

887 This Printer Status attribute provides current information about the motor sub-units, if any,
888 of the Printer. Each of the member attributes are modeled using the common Printer MIB
889 v2 [RFC3805] sub-unit properties.

890 5.4.9.1 motor-info (text(127))

891 This REQUIRED member attribute provides a localized description of the motor sub-unit.

892 5.4.9.2 motor-info-uri (uri)

893 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
894 providing additional information about the motor sub-unit.

895 5.4.9.3 motor-name (name(127))

896 This REQUIRED member attribute provides a unique name for the motor sub-unit.

897 5.4.9.4 motor-state (type1 enum)

898 This REQUIRED member attribute provides the overall state of the motor sub-unit. Values
899 are:

900 '3' ('idle'): The motor sub-unit is available and either idle or in standby mode.

901 '4' ('processing'): The motor sub-unit is available and either active or busy.

902 '5' ('stopped'): The motor sub-unit is unavailable.

903 5.4.9.5 motor-state-reasons (1setOf type2 keyword)

904 This CONDITIONALLY REQUIRED member attribute provides details concerning the
905 motor sub-unit state. Printers with more than one fan sub-unit MUST support this member
906 attribute. Values include:

907 'motor-failure': The motor has failed.

908 5.4.10 printer-platform (1setOf collection)

909 This Printer Status attribute provides current information about the Build Platform sub-
910 units, if any, of the Printer. Each of the member attributes are modeled using the common
911 Printer MIB v2 [RFC3805] sub-unit properties.

912 5.4.10.1 platform-info (text(127))

913 This REQUIRED member attribute provides a localized description of the Build Platform
914 sub-unit.

915 5.4.10.2 platform-info-uri (uri)

916 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
917 providing additional information about the Build Platform sub-unit.

918 5.4.10.3 platform-name (name(127))

919 This REQUIRED member attribute provides a unique name for the Build Platform sub-unit.

920 5.4.10.4 platform-state (type1 enum)

921 This REQUIRED member attribute provides the overall state of the Build Platform sub-unit.
922 Values are:

923 '3' ('idle'): The Build Platform sub-unit is available and either idle or in standby
924 mode.

925 '4' ('processing'): The Build Platform sub-unit is available and either active or busy.

926 '5' ('stopped'): The Build Platform sub-unit is unavailable.

927 5.4.10.5 platform-state-reasons (1setOf type2 keyword)

928 This CONDITIONALLY REQUIRED member attribute provides details concerning the Build
929 Platform sub-unit state. Printers with more than one fan sub-unit MUST support this
930 member attribute. Values include:

931 'platform-failure': The Build Platform has failed.

932 5.4.10.6 platform-temperature (integer(-273:MAX) | no-value)

933 This REQUIRED member attribute provides the current Build Platform sub-unit
934 temperature in degrees Celsius. If the Build Platform is not temperature controlled, the 'no-
935 value' value is returned.

936 5.4.11 printer-reservoir (1setOf collection)

937 This Printer Status attribute provides current information about the reservoir sub-units, if
938 any, of the Printer. Each of the member attributes are modeled using the common Printer
939 MIB v2 [RFC3805] sub-unit properties.

940 5.4.11.1 reservoir-info (text(127))

941 This REQUIRED member attribute provides a localized description of the reservoir sub-
942 unit.

943 5.4.11.2 reservoir-info-uri (uri)

944 This RECOMMENDED member attribute provides the 'http' or 'https' URI of a web page
945 providing additional information about the reservoir sub-unit.

946 5.4.11.3 reservoir-name (name(127))

947 This REQUIRED member attribute provides a unique name for the reservoir sub-unit.

948 5.4.11.4 reservoir-state (type1 enum)

949 This REQUIRED member attribute provides the overall state of the reservoir sub-unit.
950 Values are:

951 '3' ('idle'): The fan sub-unit is available and either idle or in standby mode.

952 '4' ('processing'): The fan sub-unit is available and either active or busy.

953 '5' ('stopped'): The fan sub-unit is unavailable.

954 5.4.11.5 reservoir-state-reasons (1setOf type2 keyword)

955 This CONDITIONALLY REQUIRED member attribute provides details concerning the
956 reservoir sub-unit state. Printers with more than one reservoir sub-unit MUST support this
957 member attribute. Values include:

958 'reservoir-empty': The reservoir is empty.

959 'reservoir-low': The reservoir is almost empty.

960 'reservoir-needed': The reservoir is empty but needs to be filled for a processing
961 Job.

962

963 **6. New Values for Existing Attributes**

964 **6.1 ipp-features-supported (1setOf type2 keyword)**

965 This document registers the new value 'ipp-3d'.

966 **6.2 printer-state-reasons (1setOf type2 keyword)**

967 This document registers the following new values:

968 'camera-failure': A camera is no longer working.

969 'chamber-cooling': A chamber is being cooled.

970 'chamber-heating': A chamber is being heated.

971 'chamber-temperature-high': The temperature of a chamber is high.

972 'chamber-temperature-low': The temperature of a chamber is low.

973 'cutter-at-eol': A cutter has reached its end-of-life and will need to be replaced soon.

974 'cutter-failure': A cutter has failed.

975 'cutter-near-eol': A cutter is near its end-of-life and may need to be replaced soon.

976 'extruder-cooling': An extruder is being cooled.

977 'extruder-failure': An extruder has failed and requires maintenance or replacement.

978 'extruder-heating': An extruder is being heated.

979 'extruder-jam': An extruder is jammed or clogged.

980 'extruder-temperature-high': The temperature of an extruder is too high.

981 'extruder-temperature-low': The temperature of an extruder is too low.

982 'fan-failure': A fan has failed.

983 'lamp-at-eol': A lamp has reached its end-of-life and will need to be replaced soon.

984 'lamp-failure': A lamp has failed.

985 'lamp-near-eol': A lamp is near its end-of-life and may need to be replaced soon.

986 'laser-at-eol': A laser has reached its end-of-life and will need to be replaced soon.

- 987 'laser-failure': A laser has failed.
- 988 'laser-near-eol': A laser is near its end-of-life and may need to be replaced soon.
- 989 'material-empty': One or more build materials have been exhausted.
- 990 'material-low': One or more build materials may need replenishment soon.
- 991 'material-needed': One or more build materials need to be loaded for a processing
992 Job.
- 993 'motor-failure': A motor has failed.
- 994 'reservoir-empty': One or more reservoirs are empty.
- 995 'reservoir-low': One or more reservoirs are almost empty.
- 996 'reservoir-needed': One or more reservoirs are empty but need to be filled for a
997 processing Job.
- 998 [Editor's Note: Additional keywords may be needed, for discussion]
999

1000 **7. Conformance Requirements**

1001 **7.1 Printer Conformance Requirements**

1002 **7.2 Client Conformance Requirements**

1003

1004 **8. Internationalization Considerations**

1005 For interoperability and basic support for multiple languages, conforming implementations
1006 MUST support:

- 1007 1. The Universal Character Set (UCS) Transformation Format -- 8 bit (UTF-8)
1008 [STD63] encoding of Unicode [UNICODE] [ISO10646]; and
- 1009 2. The Unicode Format for Network Interchange [RFC5198] which requires
1010 transmission of well-formed UTF-8 strings and recommends transmission of
1011 normalized UTF-8 strings in Normalization Form C (NFC) [UAX15].

1012 Unicode NFC is defined as the result of performing Canonical Decomposition (into base
1013 characters and combining marks) followed by Canonical Composition (into canonical
1014 composed characters wherever Unicode has assigned them).

1015 WARNING – Performing normalization on UTF-8 strings received from IPP Clients and
1016 subsequently storing the results (e.g., in IPP Job objects) could cause false negatives in
1017 IPP Client searches and failed access (e.g., to IPP Printers with percent-encoded UTF-8
1018 URIs now 'hidden').

1019 Implementations of this document SHOULD conform to the following standards on
1020 processing of human-readable Unicode text strings, see:

1021 Unicode Bidirectional Algorithm [UAX9] – left-to-right, right-to-left, and vertical

1022 Unicode Line Breaking Algorithm [UAX14] – character classes and wrapping

1023 Unicode Normalization Forms [UAX15] – especially NFC for [RFC5198]

1024 Unicode Text Segmentation [UAX29] – grapheme clusters, words, sentences

1025 Unicode Identifier and Pattern Syntax [UAX31] – identifier use and normalization

1026 Unicode Character Encoding Model [UTR17] – multi-layer character model

1027 Unicode in XML and other Markup Languages [UTR20] – XML usage

1028 Unicode Character Property Model [UTR23] – character properties

1029 Unicode Conformance Model [UTR33] – Unicode conformance basis+

1030 Unicode Collation Algorithm [UTS10] – sorting

1031 Unicode Locale Data Markup Language [UTS35] – locale databases

1032 **9. Security Considerations**

1033 In addition to the security considerations described in the IPP/1.1: Model and Semantics
1034 [RFC2911], the following sub-sections describe issues that are unique to 3D printing.

1035 Implementations of this specification SHOULD conform to the following standards on
1036 processing of human-readable Unicode text strings, see:

1037 Unicode Security Mechanisms [UTS39] – detecting and avoiding security attacks

1038 Unicode Security FAQ [UNISECFAQ] – common Unicode security issues

1039 **9.1 Access Control**

1040 Because of the potential for abuse and misuse, Printers SHOULD provide access control
1041 mechanisms including lists of allowed Clients, authentication, and authorization to site
1042 defined policies.

1043 **9.2 Physical Safety**

1044 Printers MUST NOT allow Clients to disable physical safety features of the hardware, such
1045 as protective gates, covers, or interlocks.

1046 **9.3 Material Safety**

1047 Printers MUST restrict usage and combination of materials to those that can be safely
1048 printed. Access controls (section 9.1) MAY be used to allow authorized users to
1049 experiment with untested materials or combinations, but only when such materials or
1050 combinations can reasonably be expected to not pose a safety risk.

1051 **9.4 Temperature Control**

1052 Printers MUST validate temperature and fan speed values provided by Clients and limit
1053 material, extruder, build platform, and print chamber temperatures within designed limits to
1054 prevent unsafe operating conditions, damage to the hardware, explosions, and/or fires.

1055

1056 10. IANA and PWG Considerations

1057 10.1 Attribute Registrations

1058 The attributes defined in this document will be published by IANA according to the
1059 procedures in IPP/1.1 Model and Semantics [RFC2911] section 6.2 in the following file:

1060 <http://www.iana.org/assignments/ipp-registrations>

1061 The registry entries will contain the following information:

1062	Document Description attributes:	Reference
1063	-----	-----
1064	name (type)	[REFERENCE]
1065		
1066	Document Status attributes:	Reference
1067	-----	-----
1068	name (type)	[REFERENCE]
1069		
1070	Document Template attributes:	Reference
1071	-----	-----
1072	name (type)	[REFERENCE]
1073		
1074	Job Description attributes:	Reference
1075	-----	-----
1076	name (type)	[REFERENCE]
1077		
1078	Job Status attributes:	Reference
1079	-----	-----
1080	name (type)	[REFERENCE]
1081		
1082	Job Template attributes:	Reference
1083	-----	-----
1084	name (type)	[REFERENCE]
1085		
1086	Operation attributes:	Reference
1087	-----	-----
1088	name (type)	[REFERENCE]
1089		
1090	Printer Description attributes:	Reference
1091	-----	-----
1092	name (type)	[REFERENCE]
1093		
1094	Printer Status attributes:	Reference
1095	-----	-----
1096	name (type)	[REFERENCE]
1097		
1098	Subscription Description attributes:	Reference
1099	-----	-----
1100	name (type)	[REFERENCE]
1101		
1102	Subscription Status attributes:	Reference
1103	-----	-----

1104	name (type)	[REFERENCE]
1105		
1106	Subscription Template attributes:	Reference
1107	-----	-----
1108	name (type)	[REFERENCE]
1109		

1110 10.2 Attribute Value Registrations

1111 The attributes defined in this document will be published by IANA according to the
 1112 procedures in IPP/1.1 Model and Semantics [RFC2911] section 6.1 in the following file:

1113 <http://www.iana.org/assignments/ipp-registrations>

1114 The registry entries will contain the following information:

1115	Attributes (attribute syntax)	
1116	Keyword Attribute Value	Reference
1117	-----	-----
1118	name (type2 keyword)	[REFERENCE]
1119	value-1	[REFERENCE]
1120	value-2	[REFERENCE]
1121	name-supported (1setOf type2 keyword)	[REFERENCE]
1122	< all name values >	[REFERENCE]

1123 10.3 Type2 enum Registrations

1124 The attributes defined in this document will be published by IANA according to the
 1125 procedures in IPP Model and Semantics [RFC2911] section 6.1 in the following file:

1126 <http://www.iana.org/assignments/ipp-registrations>

1127 The registry entries will contain the following information:

1128	Attributes (attribute syntax)	
1129	Enum Value Enum Symbolic Name	Reference
1130	-----	-----
1131	name (type2 enum)	[REFERENCE]
1132	3 value-3	[REFERENCE]
1133	4 value-4	[REFERENCE]
1134		
1135	operations-supported (1setOf type2 enum)	[RFC2911]
1136	0xXXXX Operation-Name	[REFERENCE]

1137 10.4 Operation Registrations

1138 The attributes defined in this document will be published by IANA according to the
 1139 procedures in IPP/1.1 Model and Semantics [RFC2911] section 6.4 in the following file:

1140 <http://www.iana.org/assignments/ipp-registrations>

1141 The registry entries will contain the following information:

1142	Operation Name	Reference
1143	-----	-----
1144	Operation-Name	[REFERENCE]
1145	Exiting-Operation-Name (Extension)	[REFERENCE]

1146 10.5 Status Code Registrations

1147 The attributes defined in this document will be published by IANA according to the
1148 procedures in IPP/1.1 Model and Semantics [RFC2911] section 6.6 in the following file:

1149 <http://www.iana.org/assignments/ipp-registrations>

1150 The registry entries will contain the following information:

1151	Value	Status Code Name	Reference
1152	-----	-----	-----
1153	0x0400:0x04FF - Client Error:		
1154	0x04XX client-error-name		[REFERENCE]
1155	0x0500:0x05FF - Server Error:		
1156	0x05XX server-error-name		[REFERENCE]

1157 10.6 Semantic Model Registrations

1158 The IPP attributes, values, and operations defined in this specification and listed in the
1159 preceding sections will be added to the PWG Semantic Model XML schema using the
1160 method defined in section 21 of [PWG5108.07].

1161

1162 11. References

1163 11.1 Normative References

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1196 3629/STD 63, November 2003, <http://tools.ietf.org/html/rfc3629>
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1238 **12. Author's Address**

1239 Primary author:

1240 Michael Sweet
1241 Apple Inc.
1242 1 Infinite Loop
1243 MS 111-HOMC
1244 Cupertino, CA 95014
1245 msweet@apple.com

1246 The authors would also like to thank the following individuals for their contributions to this
1247 standard:

1248 Olliver Schinagl, Ultimaker B.V.

1249

1250 **13. Object Definition Languages (ODLs)**

1251 This section provides information on several commonly used ODLs with either existing
1252 (registered) or suggested MIME media types.

1253 **13.1 3D Manufacturing Format (3MF)**

1254 3MF [3MF] is a freely-available format based on the Open Packaging Conventions that
1255 provides geometry, material, and texture information necessary to support a wide variety of
1256 3D printers. Materials can be named and composed within the geometry, facilitating
1257 multiple material support in coordination with a Job Ticket.

1258 The registered MIME media type for the original Microsoft published specification is
1259 "application/vnd.ms-3mfdocument". The suggested (but not registered) MIME media type
1260 for the 3MF Consortium's published specification is "model/3mf".

1261 **13.2 Additive Manufacturing Format (AMF)**

1262 AMF [ISO52915] is a relatively new format that was designed as a replacement for the
1263 Standard Tessellation Language (STL). Its use has been hampered by the lack of a freely-
1264 available specification, but has several advantages over STL including:

- 1265 1. Shared vertices which eliminates holes and other breaks in the surface
1266 geometry of objects,
- 1267 2. Specification of multiple materials in a single file,
- 1268 3. Curved surfaces can be specified, and
- 1269 4. Coordinates use explicit units for proper output dimensions.

1270 The suggested (but not registered) MIME media type is 'model/amf'.

1271 **13.3 Standard Tessellation Language (STL)**

1272 STL [STLFORMAT] is widely supported by existing client software. The registered MIME
1273 media type is 'application/sla'.

1274

1275 **14. Design Choices**

1276 This section documents some of the design choices that were made during the
1277 development of this specification.

1278 **14.1 "material-rate-units" Values**

1279 The list of units for the "material-rate" values was explicitly limited because larger units are
1280 unnecessary for current printers and technologies, and because additional units may pose
1281 interoperability issues.

1282 **14.2 Use of Celsius for Temperatures**

1283 The various integer attributes for temperature use degrees Celsius. This was done
1284 because most existing printers and materials are specified using degrees Celsius. There is
1285 no advantage to using degrees Fahrenheit or Kelvin, and forcing Clients and Printers to
1286 perform additional unit conversions could cause safety issues.
1287

1288 **15. Change History**

1289 **15.1 January 28, 2016**

- 1290 1. Updated to working draft template.
- 1291 2. Fixed document URLs.
- 1292 3. Global: "white paper" changed to "specification" as needed.
- 1293 4. Abstract: "this specification", extension to IPP Everywhere as well.
- 1294 5. Section 4: "3D Print Service Model", remove old intro text
- 1295 6. Dropped tables 1-3, instead just say "same as 2D print service" and mention that
- 1296 certain Job Template attributes such as "media" are not applicable to most 3D
- 1297 printers.
- 1298 7. Table 4: Added section references, reordered so that all RFC 3805 subunits are
- 1299 listed first.
- 1300 8. Section 4.x: Reword in places now that this is a specification.
- 1301 9. Section 5: Added subunit collection attributes
- 1302 10. Section 6: Add registration (instead of just suggestion)
- 1303 11. Added Section 14 on design choices

1304 **15.2 November 16, 2015**

- 1305 1. Section 1: Fix typos
- 1306 2. Section 3: Updated rationale to talk about 3MF instead of AMF and STL
- 1307 3. Section 4: Added new subsection on the 3D Print Service and the operations
- 1308 and attributes that are used.
- 1309 4. Section 4.3: Added Chambers to list of subunits since we are providing access
- 1310 to the temperature.
- 1311 5. Section 5.1.1: Added table listing all member attributes.
- 1312 6. Section 5.1.1.x: Added sections on material-amount, material-amount-units,
- 1313 material-diameter, material-rate, material-rate-units
- 1314 7. Section 5.1.1.x: Renamed "material-use" to "material-purpose" to avoid
- 1315 confusion with "material-amount-xxx".
- 1316 8. Section 5.3: Add new materials-col member attribute -supported attributes
- 1317 9. Section 7.1: Note existing MS 3DMF MIME media type
- 1318 10. Global: printer-bed-xxx -> printer-platform-xxx
- 1319 11. Global: Add range for all temperature attributes (-273:MAX)

1320 **15.3 October 29, 2015**

- 1321 1. Greatly expanded the discussion of how current solutions work and the IPP
- 1322 model
- 1323 2. Added discussion points for amount of material used
- 1324 3. Added materials-col-actual Job Description attribute
- 1325 4. Added 3MF description and reference
- 1326 5. Fixed link to IPP Everywhere in references

1327 15.4 August 12, 2015

- 1328 1. Dropped “0.1” from the title
- 1329 2. Various typographical changes
- 1330 3. Section 2.2: Added ODL acronym
- 1331 4. Table 1: Added reference column
- 1332 5. Figure 1: Updated figure to show Z increasing downward (direction of build
- 1333 platform movement)
- 1334 6. Section 4.x: Added sub-section on output intent.
- 1335 7. Section 5.1: Added table listing Job Template and corresponding -default and -
- 1336 supported attributes.
- 1337 8. Section 5.1.1.4: Added more types of filament, solid wax, and clarification on the
- 1338 names used for material type keywords.
- 1339 9. Section 5.1.1.5: Made material-use 1setOf, added 'all' value.
- 1340 10. Updated printer-bed-temperature-supported and printer-chamber-temperature-
- 1341 supported to allow 'no-value' values.
- 1342 11. Section 9.x: Added subsections on specific 3D printing security considerations.

1343 15.5 July 29, 2015

- 1344 1. Dropped all references to X3G and G-code.
- 1345 2. Reworked materials-col to specify materials but not temperatures and other
- 1346 physical properties
- 1347 3. Added “material-use” member attribute to assign materials to specific uses.
- 1348 4. Supports and rafts pick materials based on “material-use” values and not
- 1349 indices.
- 1350 5. Added reference to IPP INFRA
- 1351 6. Added printer-camera-image-uri Printer Description attribute.

1352 15.6 April 13, 2015

- 1353 1. Updated front matter to incorporate new IEEE-ISTO boilerplate for a contributed
- 1354 white paper.

1355 15.7 April 5, 2015

- 1356 1. Updated front matter to remove IEEE-ISTO boilerplate.
- 1357 2. Fixed various typos
- 1358 3. Clarified that SLC files are commonly known as STL files.
- 1359 4. Clarified that S3G is a binary version of G-code with a standard packet format.
- 1360 5. Added use case for printing with loaded materials
- 1361 6. Added use case for multi-material printing on a single material printer.
- 1362 7. Added use case for monitoring print progress visually with a web cam.
- 1363 8. Added exception for "skipping" (insufficient material flow/feed)
- 1364 9. Added exception for adhesion issues

- 1365 10. Added exception for build plate being full.
- 1366 11. Added exception for head movement issues.
- 1367 12. Added figure showing the typical coordinate system.
- 1368 13. Expanded Job Template and Printer Description details, added comments for
- 1369 discussion.
- 1370 14. Added new Unicode considerations and references.

1371 **15.8 January 23, 2015**

- 1372 Initial revision.