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IPP 3D Printing Extensions (3D)

Status: Interim

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

This document is a White Paper. For a definition of a "White Paper", see:

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

This document is available electronically at:

http://ftp.pwg.org/pub/pwg/ipp/ws/wd-sweet-ipp3d-20151116.docx
http://ftp.pwg.org/pub/pwg/ipp/ws/wd-sweet-ipp3d-20151116.pdf

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

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1. Introduction

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

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

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

This document does not address the larger issue of choosing a common Object Definition Language (ODL) for interoperability, however there are suggested MIME media type names listed in section 7 for several formats in common use as well as strategies for mapping material definitions in the Job Ticket to the ODL content.

1.1 Previous Solutions

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

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

186   **2. Terminology**

187   **2.1 3D Printing Terminology**

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

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

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

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

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

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

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

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

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

206   **2.2 Acronyms and Organizations**

207   *CNC*: Computer Numerical Control

208   *DLP*: Digital Light Processing

209   *FDM*: Fused Deposition Modeling

210   *IANA*: Internet Assigned Numbers Authority, http://www.iana.org/

211   *IETF*: Internet Engineering Task Force, http://www.ietf.org/

212   *ISO*: International Organization for Standardization, http://www.iso.org/

213   *ODL*: Object Definition Language

214   *PWG*: Printer Working Group, http://www.pwg.org/

215   *SD*: SD Card Association, http://www.sdcard.org/

216   *SDL*: Selective Deposition Lamination

217   *SL*: Stereo Lithography

218   *USB*: Universal Serial Bus, http://www.usb.org/
219

220 # 3. Rationale for IPP 3D Printing Extensions

221 Existing specifications define the following:

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

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

236 ## 3.1 Use Cases

237 ### 3.1.1 Print a 3D Object

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

241 ### 3.1.2 Print a 3D Object Using Loaded Materials

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

245 ### 3.1.3 Print a 3D Object with Multiple Materials

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

250 ### 3.1.4 View a 3D Object During Printing

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

3.2 Exceptions

3.2.1 Clogged Extruder

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

3.2.2 Extruder Temperature Out of Range

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

3.2.3 Extruder Head Movement Issues

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

3.2.4 Filament Feed Jam

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

3.2.5 Filament Feed Skip

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

3.2.6 Material Empty

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

3.2.7 Material Adhesion Issues

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

284   **3.2.8 Print Bed Temperature Out of Range**

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

288   **3.2.9 Print Bed Not Clear**

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

293   ## 3.3 Out of Scope

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

295   1. Definition of new file formats; and
296   2. Support for Subtractive Manufacturing technologies such as CNC milling
297   machines.

298   ## 3.4 Design Requirements

299   The design requirements for this document are:

300   3. Define attributes and values to describe supported and loaded (ready) materials
301   used for FDM; and
302   4. Define attributes and values to describe FDM printer capabilities and state

303   The design recommendations for this document are:

304   1. Support 3D printing technologies other than FDM

305

306 **4. Technical Solutions/Approaches**

307 Current 3D printers offer limited connectivity and status monitoring capabilities. Many
308 printers simply read printer-ready files from SD memory cards, with all interaction and
309 status monitoring happening at the printer's console.

310 Makerbot Industries uses a proprietary protocol and file format that generalizes some
311 aspects of the interface between a host device and 3D printer. However, this solution is
312 highly specific to FDM printing and does not offer any spooling or security functionality.

313 Various other proprietary protocols and interfaces are also in use, typically based on the
314 USB serial protocol class for direct connection to a host device. And there are a number of
315 Cloud-based solutions emerging that utilize a proxy device that communicates with the
316 Cloud and 3D printer.

317 Given that the 3D printing industry and technologies are still undergoing a great deal of
318 change and development, certain aspects of 3D printing may be difficult or infeasible to
319 standardize. However, a stable, reliable, and secure interface between host device (IPP
320 Client) and 3D printer (IPP Printer) can be defined today in a way that allows for future
321 changes to be incorporated without difficulty.

322 **4.1 High-Level Model**

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

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

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

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

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

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

349
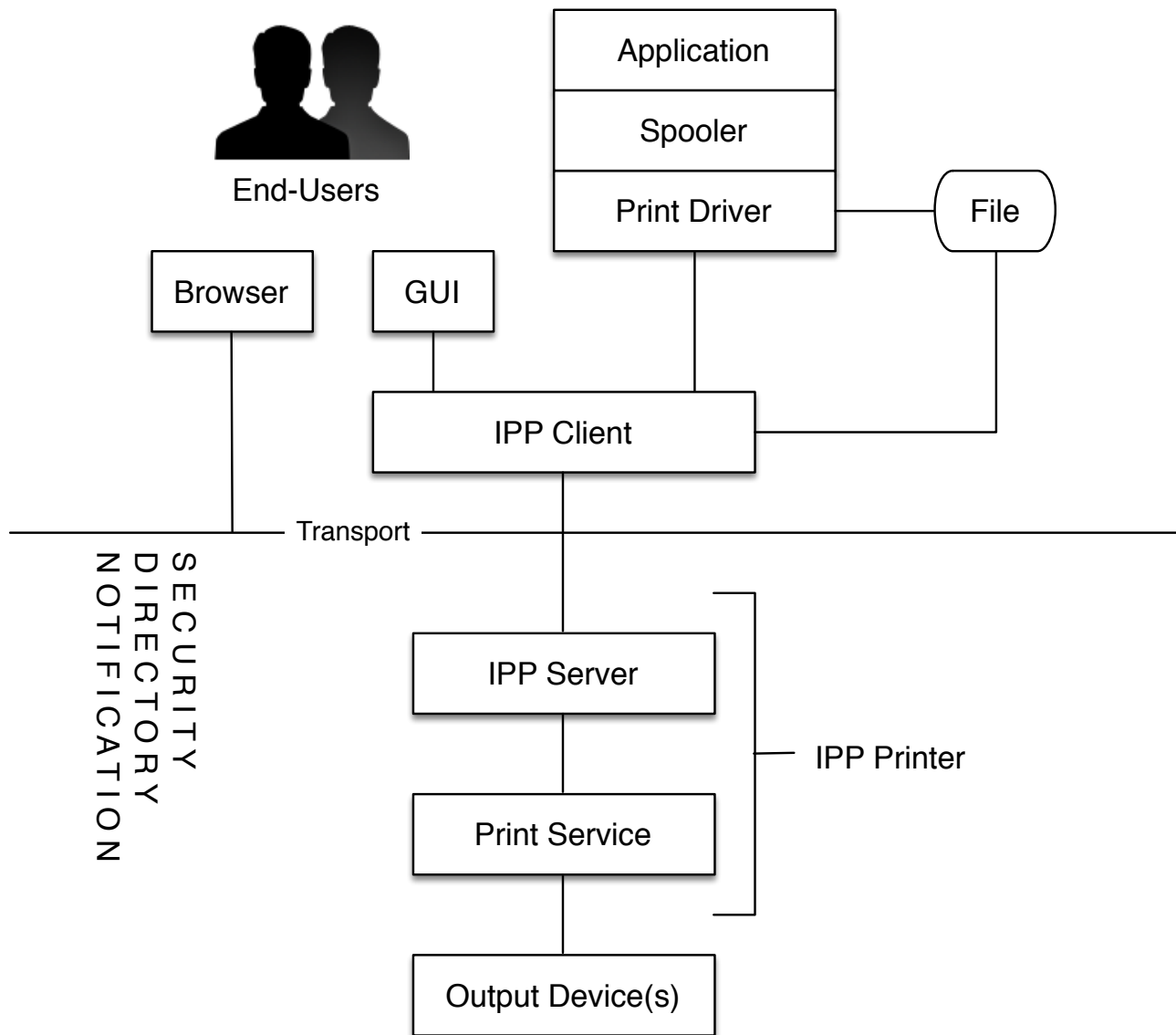
350

351   **Figure 1 - Generalized IPP Model (RFC 2911)**

352 **4.2 3D Print Service**

353 3D printing uses a variation of the traditional Print service that maintains state and
354 capability information specific to 3D printing. Table 1 lists the operations that are used by
355 the 3D Print service. Table 2 lists additional operations that are used by Cloud-based
356 services. And Table 3 lists the various attributes that are used by all 3D Print services.

357   **Table 1 - 3D Print Service Operations**

Code	Operation Name	Reference
0x0004	Validate-Job	RFC 2911
0x0005	Create-Job	RFC 2911
0x0006	Send-Document	RFC 2911
0x0007	Send-URI	RFC 2911
0x0008	Cancel-Job	RFC 2911
0x0009	Get-Job-Attributes	RFC 2911
0x000A	Get-Jobs	RFC 2911
0x000B	Get-Printer-Attributes	RFC 2911
0x000C	Hold-Job	RFC 2911
0x000D	Release-Job	RFC 2911
0x0010	Pause-Printer	RFC 2911
0x0011	Resume-Printer	RFC 2911
0x0013	Set-Printer-Attributes	RFC 3380
0x0014	Set-Job-Attributes	RFC 3380
0x0015	Get-Printer-Supported-Values	RFC 3380
0x0016	Create-Printer-Subscriptions	RFC 3995
0x0017	Create-Job-Subscriptions	RFC 3995
0x0018	Get-Subscription-Attributes	RFC 3995
0x0019	Get-Subscriptions	RFC 3995
0x001A	Renew-Subscription	RFC 3995
0x001B	Cancel-Subscription	RFC 3995
0x001C	Get-Notifications	RFC 3996
0x0022	Enable-Printer	RFC 3998
0x0023	Disable-Printer	RFC 3998
0x0024	Pause-Printer-After-Current-Job	RFC 3998
0x0025	Hold-New-Jobs	RFC 3998
0x0026	Release-Held-New-Jobs	RFC 3998
0x002D	Cancel-Current-Job	RFC 3998
0x0038	Cancel-Jobs	PWG 5100.11
0x0039	Cancel-My-Jobs	PWG 5100.11
0x003A	Resubmit-Job	PWG 5100.11
0x003B	Close-Job	PWG 5100.11
0x003C	Identify-Printer	PWG 5100.13

358

359

360   **Table 2 - Additional Cloud-Based 3D Print Service Operations**

Code	Operation Name	Reference
0x003F	Acknowledge-Document	PWG 5100.18
0x0040	Acknowledge-Identify-Printer	PWG 5100.18
0x0041	Acknowledge-Job	PWG 5100.18
0x0042	Fetch-Document	PWG 5100.18
0x0043	Fetch-Job	PWG 5100.18
0x0044	Get-Output-Device-Attributes	PWG 5100.18
0x0045	Update-Active-Jobs	PWG 5100.18
0x0046	Deregister-Output-Device	PWG 5100.18
0x0047	Update-Document-Status	PWG 5100.18
0x0048	Update-Job-Status	PWG 5100.18
0x0049	Update-Output-Device-Attributes	PWG 5100.18

361

362   **Table 3 - 3D Print Service Attributes**

Attribute Name	Object	Reference
attributes-charset	All/operation	RFC 2911
attributes-natural-language	All/operation	RFC 2911
charset-configured	Printer	RFC 2911
charset-supported	Printer	RFC 2911
compression	operation	RFC 2911
compression-supported	Printer	RFC 2911
document-format	Document/operation	RFC 2911
document-format-default	Printer	RFC 2911
document-format-supported	Printer	RFC 2911
document-name	Job/Document/ operation	RFC 2911
generated-natural-language-supported	Printer	RFC 2911
ipp-attribute-fidelity	operation	RFC 2911
ipp-features-supported	Printer	PWG 5100.13
ipp-versions-supported	Printer	RFC 2911
job-id	Job	RFC 2911
job-name	Job/operation	RFC 2911
job-originating-user-name	Job	RFC 2911
job-printer-up-time	Job	RFC 2911
job-state	Job	RFC 2911
job-state-reasons	Job	RFC 2911
job-state-message	Job	RFC 2911
limit	operation	RFC 2911
my-jobs	operation	RFC 2911
natural-language-configured	Printer	RFC 2911
operations-supported	Printer	RFC 2911
pdl-override-supported	Printer	RFC 2911
pdl-override-guaranteed-supported	Printer	IANA

Attribute Name	Object	Reference
printer-is-accepting-jobs	Printer	RFC 2911
printer-name	Printer	RFC 2911
printer-state	Printer	RFC 2911
printer-state-message	Printer	RFC 2911
printer-state-reasons	Printer	RFC 2911
printer-current-time	Printer	RFC 2911
printer-up-time	Printer	RFC 2911
printer-uri	operation	RFC 2911
printer-uri-supported	Printer	RFC 2911
queued-job-count	Printer	RFC 2911
requested-attributes	operation	RFC 2911
requesting-user-name	operation	RFC 2911
date-time-at-completed	Job	RFC 2911
date-time-at-creation	Job	RFC 2911
date-time-at-processing	Job	RFC 2911
time-at-completed	Job	RFC 2911
time-at-creation	Job	RFC 2911
time-at-processing	Job	RFC 2911
uri-authentication-supported	Printer	RFC 2911
uri-security-supported	Printer	RFC 2911
printer-xri-supported	Printer	RFC 3380
which-jobs	operation	RFC 2911
print-quality	Job	RFC 2911
print-quality-default	Job	RFC 2911
print-quality-supported	Job	RFC 2911
color-supported	Printer	RFC 2911
copies	Job	RFC 2911
copies-default	Printer	RFC 2911
copies-supported	Printer	RFC 2911
finishings	Job	RFC 2911
finishings-supported	Printer	RFC 2911
finishings-default	Printer	RFC 2911
job-creation-attributes-supported	Printer	PWG 5100.11
printer-alert	Printer	PWG 5100.9
printer-alert-description	Printer	PWG 5100.9
printer-info	Printer	RFC 2911
printer-location	Printer	RFC 2911
printer-geo-location	Printer	PWG 5100.13
printer-make-and-model	Printer	RFC 2911
printer-more-info	Printer	RFC 2911
status-message	operation	RFC 2911
ippget-event-life	Printer	RFC 3996
job-hold-until	Job	RFC 2911
job-hold-until-supported	Printer	RFC 2911
job-hold-until-default	Printer	RFC 2911

Attribute Name	Object	Reference
job-ids	operation	PWG 5100.11
job-ids-supported	Printer	PWG 5100.11
job-priority	Job	RFC 2911
job-priority-default	Printer	RFC 2911
job-priority-supported	Printer	RFC 2911
job-settable-attributes-supported	Printer	RFC 3380
printer-settable-attributes-supported	Printer	RFC 3380
last-document	operation	RFC 2911
multiple-operation-time-out	Printer	RFC 2911
multiple-operation-time-out-action	Printer	PWG 5100.13
notify-charset	Subscription	RFC 3995
notify-events	Subscription	RFC 3995
notify-events-default	Printer	RFC 3995
notify-events-supported	Printer	RFC 3995
notify-get-interval	operation	RFC 3996
notify-job-id	Subscription	RFC 3995
notify-lease-duration	Subscription	RFC 3995
notify-lease-duration-default	Printer	RFC 3995
notify-lease-duration-supported	Printer	RFC 3995
notify-lease-expiration-time	Subscription	RFC 3995
notify-max-events-supported	Printer	RFC 3995
notify-natural-language	Subscription	RFC 3995
notify-printer-up-time	Subscription	RFC 3995
notify-printer-uri	Subscription	RFC 3995
notify-pull-method	Subscription	RFC 3995
notify-pull-method-supported	Printer	RFC 3995
notify-sequence-number	Subscription	RFC 3995
notify-sequence-numbers	operation	RFC 3995
notify-status-code	operation	RFC 3995
notify-subscribed-event	Subscription	RFC 3995
notify-subscriber-user-name	Subscription	RFC 3995
notify-subscription-id	Subscription	RFC 3995
notify-subscriptions-ids	operation	RFC 3996
notify-text	Subscription	RFC 3995
notify-time-interval	Subscription	RFC 3995
notify-user-data	Subscription	RFC 3995
notify-wait	operation	RFC 3996
output-device-supported	Printer	RFC 2911
output-device-assigned	Job	RFC 3998
printer-state-change-date-time	Printer	RFC 3995
printer-state-change-time	Printer	RFC 3995
printer-config-change-date-time	Printer	PWG 5100.13
printer-config-change-time	Printer	PWG 5100.13
which-jobs-supported	Printer	PWG 5100.11
printer-get-attributes-supported	Printer	PWG 5100.13

Attribute Name	Object	Reference
printer-icons	Printer	PWG 5100.13
printer-organization	Printer	PWG 5100.13
printer-organizational-unit	Printer	PWG 5100.13
printer-uuid	Printer	PWG 5100.13
job-uuid	Job	PWG 5100.13
notify-subscription-uuid	Subscription	PWG 5100.13
printer-mandatory-job-attributes	Printer	PWG 5100.13
printer-supply	Printer	PWG 5100.13
printer-supply-description	Printer	PWG 5100.13
printer-supply-info-uri	Printer	PWG 5100.13
compression-accepted	operation	PWG 5100.17
document-format-accepted	operation	PWG 5100.17
document-number	operation	PWG 5100.5
document-preprocessed	operation	PWG 5100.18
document-uri	operation	RFC 2911
fetch-status-code	operation	PWG 5100.18
fetch-status-message	operation	PWG 5100.18
first-index	operation	PWG 5100.13
identify-actions	operation	PWG 5100.13
identify-actions-default	Printer	PWG 5100.13
identify-actions-supported	Printer	PWG 5100.13
output-device-job-states	operation	PWG 5100.18
output-device-uuid	operation	PWG 5100.18
printer-static-resource-directory-uri	Printer	PWG 5100.18
printer-static-resource-k-octets-supported	Printer	PWG 5100.18
printer-static-resource-k-octets-free	Printer	PWG 5100.18

363 ## 4.3 3D Printer Subunits

364 Table 4 lists the subunits of 3D printers for different technologies.

365 **Table 4 - 3D Printer Subunits**

Subunit	Technology	Reference
Build Platforms	All	<none>
Cameras	All	<none>
Chamber	All	<none>
Cutters	SDL	RFC 3806
Doors	All	RFC 3805
Fans	FDM	<none>
Input Trays	SDL	RFC 3805
Lamps	DLP	<none>
Lasers	Laser Sintering, SL	<none>
Marker Supplies	All	RFC 3805
Markers (or Extruders)	Many	RFC 3805

Subunit	Technology	Reference
Media Path	SDL	RFC 3805
Motors	All	<none>
Reservoirs	DLP, Laser Sintering, SL	<none>

4.3.1 Build Platforms

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

4.3.2 Cameras

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

4.3.3 Chambers

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

4.3.4 Cutters

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

4.3.5 Fans

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

4.3.6 Lamps

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

4.3.7 Lasers

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

4.3.8 Markers (or Extruders)

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

391 **4.3.9 Motors**

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

393 **4.3.10 Reservoirs**

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

395 ## 4.4 3D Printer Coordinate System

396 3D printers operate in three dimensions and thus have three axis of movement. Figure 2
397 shows a typical coordinate system where the X axis represents the width of the object, the
398 Y axis represents the depth of the object, and the Z axis represents the height of the
399 object. Note that, depending on the technology used, the Z axis may move in the opposite
400 direction, or the extruder may move independently with a stationary build platform.

401
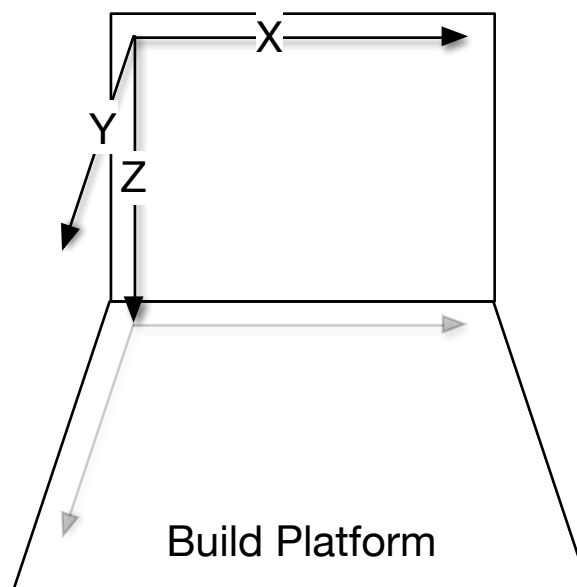
402

403 **Figure 2 - Typical Build Platform Coordinate System**

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

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

410 **4.5 Output Intent and Job Processing**

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

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

421 **4.6 Job Spooling**

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

425 **4.7 Cloud-Based Printing**

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

431 Snapshots of camera video can be uploaded as JPEG image resources using HTTP PUT
432 requests from the Proxy to the Infrastructure Printer. Such resources need to be updated
433 in an atomic fashion to allow Clients to safely poll for updates to the camera video.
434

435 **5. New Attributes**

436 **5.1 Job Template Attributes**

437 Table 5 lists the Job Template attributes and their corresponding "–default" and "-
438 supported" attributes.

439 **Table 5 - 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)

5.1.1 materials-col (1setOf collection)

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

The Client typically supplies "materials-col" values matching those returned in the "materials-col-database" (section 5.3.1) or "materials-col-ready" (section 5.3.10) Printer Description attributes. Table 6 lists the member attributes.

Table 6 - "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

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

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

5.1.1.2 material-amount-units (type2 keyword)

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

'g': Value is mass in grams.

'kg': Value is mass in kilograms.

'l': Value is volume in liters.

'm': Value is length in meters.

461   'ml': Value is volume in milliliters.

462   'mm': Value is length in millimeters.

5.1.1.3 material-color (type2 keyword)

464 This member attribute provides a PWG media color value representing the color of the
465 material.

466 material-diameter (integer(1:MAX))

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

5.1.1.4 material-key (keyword)

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

5.1.1.5 material-name (name(MAX))

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

5.1.1.6 material-purpose (1setOf type2 keyword)

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

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

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

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

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

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

5.1.1.7 material-rate (integer(1:MAX))

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

5.1.1.8 material-rate-units (type2 keyword)

485 This member attribute provides the units for the "material-rate" member attribute. Values
486 include:

487   'mg': Value is milligrams per second.

488   'ml': Value is milliliters per second.

489   'mm': Value is millimeters per second.

5.1.1.9 material-temperature (integer(-273:MAX) | rangeOfInteger(-273:MAX))
490

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

5.1.1.10 material-type (type2 keyword)
493

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

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

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

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

501   'chocolate_powder': Chocolate powder.

502   'gold_powder': Gold (metal) powder.

503   'nylon_filament': Nylon filament.

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

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

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

507   'pla-conductive_filament': Conductive PLA filament.

508   'pla-dissolvable_filament': Dissolvable PLA filament.

509   'pla-flexible_filament': Flexible PLA filament.

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

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

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

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

514   'polycarbonate_filament': Polycarbonate filament.

515   'silver_powder': Silver (metal) powder.

516   'titanium_powder': Titanium (metal) powder.

517   'wax_solid': Solid wax.

518   **5.1.2 print-fill-density (integer(0:100))**

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

520   **5.1.3 print-fill-thickness (integer(0:MAX))**

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

523   **5.1.4 print-layer-thickness (integer(0:MAX))**

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

526   **5.1.5 print-rafts (type2 keyword)**

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

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

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

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

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

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

535   **5.1.6 print-shell-thickness (integer(0:MAX))**

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

538   **5.1.7 print-speed (integer(1:MAX))**

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

540   **5.1.8 print-supports (type2 keyword)**

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

543   'none': Do not print supports.

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

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

546   **5.1.9 printer-chamber-temperature (integer(-273:MAX) | no-value)**

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

549   **5.1.10 printer-fan-speed (integer(0:100))**

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

552   **5.1.11 printer-platform-temperature (integer(-273:MAX) | no-value)**

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

555   ## 5.2 Job Description Attributes

556   **5.2.1 materials-col-actual (1setOf collection)**

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

558   ## 5.3 Printer Description Attributes

559   **5.3.1 material-amount-units-supported (1setOf type2 keyword)**

560   This Printer Description attribute lists the supported "material-amount-units" values for the
561   Printer.

562   **5.3.2 material-diameter-supported (1setOf (integer | rangeOfInteger))**

563   This Printer Description attribute lists the supported "material-diameter" values for the
564   Printer.

565   **5.3.3 material-purpose-supported (1setOf type2 keyword)**

566   This Printer Description attribute lists the supported "material-purpose" values for the
567   Printer.

568   **5.3.4 material-rate-supported (1setOf (integer | rangeOfInteger)**

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

570 **5.3.5 material-rate-units-supported (1setOf type2 keyword)**

571 This Printer Description attribute lists the supported "material-rate-units" values for the
572 Printer.

573 **5.3.6 material-temperature-supported (1setOf (integer(-273:MAX) | rangeOfInteger(-**
574 **273:MAX)))**

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

577 **5.3.7 material-type-supported (1setOf type2 keyword)**

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

579 **5.3.8 materials-col-database (1setOf collection)**

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

583 **5.3.9 materials-col-default (1setOf collection)**

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

586 **5.3.10 materials-col-ready (1setOf collection)**

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

589 **5.3.11 materials-col-supported (1setOf type2 keyword)**

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

592 **5.3.12 print-fill-density-default (integer(0:100))**

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

594 **5.3.13 print-fill-thickness-default (integer(0:MAX))**

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

597 **5.3.14 print-fill-thickness-supported (1setOf (integer(0:MAX) |**
598 **rangeOfInteger(0:MAX)))**

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

601 **5.3.15 print-layer-order (type1 keyword)**

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

604 **5.3.16 print-layer-thickness-default (integer(0:MAX))**

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

607 **5.3.17 print-layer-thickness-supported (1setOf (integer(0:MAX) |**
608 **rangeOfInteger(0:MAX)))**

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

611 **5.3.18 print-rafts-default (type2 keyword)**

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

613 **5.3.19 print-rafts-supported (1setOf type2 keyword)**

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

615 **5.3.20 print-shell-thickness-default (integer(0:MAX))**

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

618 **5.3.21 print-shell-thickness-supported (1setOf (integer(0:MAX) |**
619 **rangeOfInteger(0:MAX)))**

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

622 **5.3.22 print-speed-default (integer(1:MAX))**

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

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

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

5.3.24 print-supports-default (type2 keyword)

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

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

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

5.3.26 printer-accuracy-supported (collection)

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

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

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

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

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

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

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

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

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

5.3.31 printer-fan-speed-supported (boolean)

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

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

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

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

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

5.3.34 printer-volume-supported (collection)

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

5.4 Printer Status Attributes

[Editor's note: May be useful to change these to pairs of printer-xxx and printer-xxx-description attributes, like we do for printer-alert, printer-input-tray, printer-output-tray, printer-supply, etc. That will also provide a mapping to potential MIB extensions...]

5.4.1 printer-chamber-temperature-current (integer | no-value)

This Printer Status attribute provides the current print chamber temperature in degrees Celsius. If the print chamber is not temperature controlled, the 'no-value' value is returned.

5.4.2 printer-fan-speed-current (integer(0:100))

This Printer Status attribute provides the current fan speed in percent.

5.4.3 printer-head-temperature-current (1setOf (integer | no-value))

This Printer Status attribute provides the current extruder head temperatures in degrees Celsius. The 'no-value' value is returned when the extruder head is not temperature controlled.

5.4.4 printer-platform-temperature-current (integer(-273:MAX) | no-value)

This Printer Status attribute provides the current Build Platform temperature in degrees Celsius. If the Build Platform is not temperature controlled, the 'no-value' value is returned.

6. New Values for Existing Attributes

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

This document suggests (but does not register) the new value 'ipp-3d'.

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

This document suggests (but does not register) the following new values:

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

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

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

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

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

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

'cutter-failure': A cutter has failed.

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

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

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

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

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

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

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

'fan-failure': A fan has failed.

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

'lamp-failure': A lamp has failed.

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

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

707   'laser-failure': A laser has failed.

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

709   'material-empty': One or more build materials have been exhausted.

710   'material-low': One or more build materials may need replenishment soon.

711   'material-needed': One or more build materials need to be loaded for a processing
712   Job.

713   'motor-failure': A motor has failed.

714   'reservoir-empty': One or more reservoirs are empty.

715   'reservoir-low': One or more reservoirs are almost empty.

716   'reservoir-needed': One or more reservoirs are empty but need to be filled for a
717   processing Job.

718   [Editor's Note: Additional keywords may be needed, for discussion]

719   7. Object Definition Languages (ODLs)

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

722   7.1 3D Manufacturing Format (3MF)

723   3MF [3MF] is a freely-available format based on the Open Packaging Conventions that
724   provides geometry, material, and texture information necessary to support a wide variety of
725   3D printers. Materials can be named and composed within the geometry, facilitating
726   multiple material support in coordination with a Job Ticket.

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

730   7.2 Additive Manufacturing Format (AMF)

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

734   1. Shared vertices which eliminates holes and other breaks in the surface
735   geometry of objects,

736   2. Specification of multiple materials in a single file,
737   3. Curved surfaces can be specified, and
738   4. Coordinates use explicit units for proper output dimensions.

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

740   7.3 Standard Tessellation Language (STL)

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

743   8. Internationalization Considerations

744   For interoperability and basic support for multiple languages, conforming implementations
745   MUST support:

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

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

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

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

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

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

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

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

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

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

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

767   Unicode Character Property Model [UTR23] – character properties

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

769   Unicode Collation Algorithm [UTS10] – sorting

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

771 # 9. Security Considerations

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

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

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

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

778 ## 9.1 Access Control

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

782 ## 9.2 Physical Safety

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

785 ## 9.3 Material Safety

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

790 ## 9.4 Temperature Control

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

10. References

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879   **12. Change History**

880   **12.1 November 16, 2015**

881   1. Section 1: Fix typos
882   2. Section 3: Updated rationale to talk about 3MF instead of AMF and STL
883   3. Section 4: Added new subsection on the 3D Print Service and the operations
884   and attributes that are used.
885   4. Section 4.3: Added Chambers to list of subunits since we are providing access
886   to the temperature.
887   5. Section 5.1.1: Added table listing all member attributes.
888   6. Section 5.1.1.x: Added sections on material-amount, material-amount-units,
889   material-diameter, material-rate, material-rate-units
890   7. Section 5.1.1.x: Renamed "material-use" to "material-purpose" to avoid
891   confusion with "material-amount-xxx".
892   8. Section 5.3: Add new materials-col member attribute -supported attributes
893   9. Section 7.1: Note existing MS 3DMF MIME media type
894   10. Global: printer-bed-xxx -> printer-platform-xxx
895   11. Global: Add range for all temperature attributes (-273:MAX)

896   **12.2 October 29, 2015**

897   1. Greatly expanded the discussion of how current solutions work and the IPP
898   model
899   2. Added discussion points for amount of material used
900   3. Added materials-col-actual Job Description attribute
901   4. Added 3MF description and reference
902   5. Fixed link to IPP Everywhere in references

903   **12.3 August 12, 2015**

904   1. Dropped "0.1" from the title
905   2. Various typographical changes
906   3. Section 2.2: Added ODL acronym
907   4. Table 1: Added reference column
908   5. Figure 1: Updated figure to show Z increasing downward (direction of build
909   platform movement)
910   6. Section 4.x: Added sub-section on output intent.
911   7. Section 5.1: Added table listing Job Template and corresponding -default and -
912   supported attributes.
913   8. Section 5.1.1.4: Added more types of filament, solid wax, and clarification on the
914   names used for material type keywords.
915   9. Section 5.1.1.5: Made material-use 1setOf, added 'all' value.
916   10. Updated printer-bed-temperature-supported and printer-chamber-temperature-
917   supported to allow 'no-value' values.

918   11. Section 9.x: Added subsections on specific 3D printing security considerations.

12.4 July 29, 2015

919

920   1. Dropped all references to X3G and G-code.
921   2. Reworked materials-col to specify materials but not temperatures and other
922   physical properties
923   3. Added "material-use" member attribute to assign materials to specific uses.
924   4. Supports and rafts pick materials based on "material-use" values and not
925   indices.
926   5. Added reference to IPP INFRA
927   6. Added printer-camera-image-uri Printer Description attribute.

12.5 April 13, 2015

928

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

12.6 April 5, 2015

931

932   1. Updated front matter to remove IEEE-ISTO boilerplate.
933   2. Fixed various typos
934   3. Clarified that SLC files are commonly known as STL files.
935   4. Clarified that S3G is a binary version of G-code with a standard packet format.
936   5. Added use case for printing with loaded materials
937   6. Added use case for multi-material printing on a single material printer.
938   7. Added use case for monitoring print progress visually with a web cam.
939   8. Added exception for "skipping" (insufficient material flow/feed)
940   9. Added exception for adhesion issues
941   10. Added exception for build plate being full.
942   11. Added exception for head movement issues.
943   12. Added figure showing the typical coordinate system.
944   13. Expanded Job Template and Printer Description details, added comments for
945   discussion.
946   14. Added new Unicode considerations and references.

12.7 January 23, 2015

947

948   Initial revision.

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