The Printer Working Group

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White Paper

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-20150812.docx
http://ftp.pwg.org/pub/pwg/ipp/ws/wd-sweet-ipp3d-20150812.pdf

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 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.

2. Terminology

2.1 Terms Used in This Document

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

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

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

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

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

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

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

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

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

2.2 Acronyms and Organizations

CNC: Computer Numerical Control

DLP: Digital Light Processing

FDM: Fused Deposition Modeling

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

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

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

ODL: Object Definition Language

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

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

SDL: Selective Deposition Lamination

SL: Stereo Lithography

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

3. Rationale for IPP 3D Printing Extensions

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 Standard Specification for Additive Manufacturing File Format (AMF) Version 1.1 [ISO52915] defines an XML schema and file format for describing 3D objects with one or more materials; and
5. The SLC File Specification [STLFORMAT] defines a file format (commonly called "STL files") for describing 3D object with a single material.

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

3.1 Use Cases

3.1.1 Print a 3D Object

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

3.1.2 Print a 3D Object Using Loaded Materials

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

3.1.3 Print a 3D Object with Multiple Materials

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

3.1.4 View a 3D Object During Printing

Jane has submitted a 3D print Job that will take 4 hours to complete. She can visually 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.

253 **3.2.8 Print Bed Temperature Out of Range**

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

257 **3.2.9 Print Bed Not Clear**

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

262 3.3 Out of Scope

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

264 1. Definition of new file formats; and
265 2. Support for Subtractive Manufacturing technologies such as CNC milling
266 machines.

267 3.4 Design Requirements

268 The design requirements for this document are:

269 1. Define attributes and values to describe supported and loaded (ready) materials
270 used for FDM; and
271 2. Define attributes and values to describe FDM printer capabilities and state

272 The design recommendations for this document are:

273 1. Support 3D printing technologies other than FDM
274

4. Technical Solutions/Approaches

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

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

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

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

4.1 High-Level Model

IPP [RFC2911], the IETF Printer MIB [RFC3805], and the IETF Finisher MIB [RFC3806] already define a comprehensive model for the operation and data elements of a typical 2D printer. The IPP Job processing model matches how 3D printers process Jobs and Documents. However, more types of subunits are used in a 3D printer, requiring additions to the model and state values. Table 1 lists the subunits of 3D printers for different technologies.

Table 1 - 3D Printer Subunits

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

299 **4.1.1 Build Platforms**

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

302 **4.1.2 Cameras**

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

305 **4.1.3 Cutters**

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

308 **4.1.4 Fans**

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

311 **4.1.5 Lamps**

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

314 **4.1.6 Lasers**

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

317 **4.1.7 Markers (or Extruders)**

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

321 **4.1.8 Motors**

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

323 **4.1.9 Reservoirs**

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

4.2 Coordinate System

3D printers operate in three dimensions and thus have three axis of movement. Figure 1 shows the coordinate system where the X axis represents the width of the object, the Y axis represents the depth of the object, and the Z axis represents the height of the object.

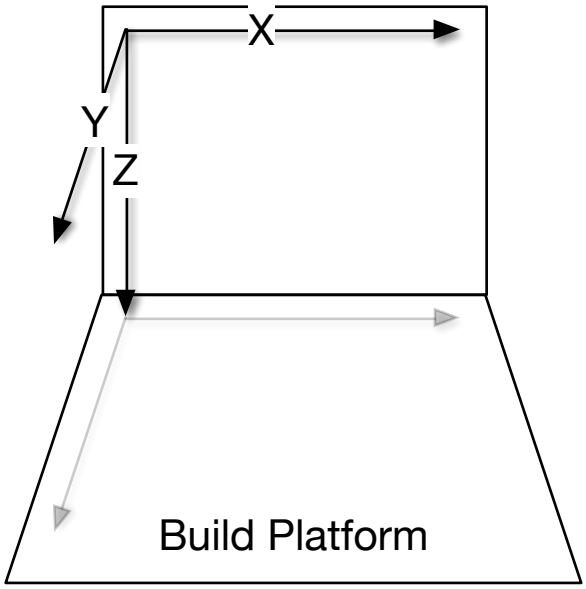

Figure 1 - Typical Build Platform Coordinate System

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

4.3 Output Intent

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

4.4 Cloud-Based Printing

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

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

349 5. New Attributes

350 5.1 Job Template Attributes

351 Table 2 lists the Job Template attributes and their corresponding "–default" and "-
352 supported" attributes.

353 **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)

Job Template	Printer: Default	Printer: Supported
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 5.2.1) or "materials-col-ready" (section 5.2.3) Printer Description attributes.

5.1.1.1 material-color (type2 keyword)

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

5.1.1.2 material-key (keyword)

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

5.1.1.3 material-name (name(MAX))

This member attribute provides a localized name of the material.

5.1.1.4 material-type (type2 keyword)

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

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

‘abs-carbon-fiber_filament’: ABS filament reinforced with carbon fibers.

‘abs-carbon-nanotube_filament’: ABS filament reinforced with carbon nanotubes.

'chocolate_powder': Chocolate powder.

'gold_powder': Gold (metal) powder.

‘nylon_filament’: Nylon filament.

‘pet_filament’: Polyethylene terephthalate (PET) filament.

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

'pla_filament': Polylactic Acid (PLA) filament.

'pla-conductive_filament': Conductive PLA filament.

‘pla-dissolvable_filament’: Dissolvable PLA filament.

'pla-flexible_filament': Flexible PLA filament.

‘pla-magnetic_filament’: PLA with embedded iron particles.

‘pla-steel-filament’: PLA with embedded steel particles.

‘pla-stone_filament’: PLA filament with embedded stone chips.

‘pla-wood_filament’: PLA filament with embedded wood fibers.

‘polycarbonate_filament’: Polycarbonate filament.

'silver_powder': Silver (metal) powder.

‘titanium_powder’: Titanium (metal) powder.

'wax_solid': Solid wax.

5.1.1.5 material-use (1setOf type2 keyword)

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

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

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

‘raft’: The material will be used to print a raft under the printed object.

‘shell’: The material will be used for the surface of the printed object.

‘support’: The material will be used to support the printed object.

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

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

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

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

[Editor's note: One comment requested speed/layer thickness attributes for in-fill, shells, and supports.]

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

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

5.1.5 print-rafts (type2 keyword)

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

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

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

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

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

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

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

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

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

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

5.1.8 print-supports (type2 keyword)

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

'none': Do not print supports.

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

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

433 **5.1.9 printer-bed-temperature (integer | no-value)**

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

436 **5.1.10 printer-chamber-temperature (integer | no-value)**

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

439 **5.1.11 printer-fan-speed (integer(0:100))**

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

442 ## 5.2 Printer Description Attributes

443 **5.2.1 materials-col-database (1setOf collection)**

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

447 **5.2.2 materials-col-default (1setOf collection)**

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

450 **5.2.3 materials-col-ready (1setOf collection)**

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

453 **5.2.4 materials-col-supported (1setOf type2 keyword)**

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

456 **5.2.5 material-type-supported (1setOf type2 keyword)**

457 This Printer Description attribute lists the supported “material-type” values for the Printer.

458 **5.2.6 material-use-supported (1setOf type2 keyword)**

459 This Printer Description attribute lists the supported “material-use” values for the Printer.

5.2.7 print-fill-density-default (integer(0:100))

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

5.2.8 print-fill-thickness-default (integer(0:MAX))

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

5.2.9 print-fill-thickness-supported (1setOf (integer(0:MAX) | rangeOfInteger(0:MAX)))

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

5.2.10 print-layer-order (type1 keyword)

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

5.2.11 print-layer-thickness-default (integer(0:MAX))

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

5.2.12 print-layer-thickness-supported (1setOf (integer(0:MAX) | rangeOfInteger(0:MAX)))

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

5.2.13 print-rafts-default (type2 keyword)

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

5.2.14 print-rafts-supported (1setOf type2 keyword)

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

5.2.15 print-shell-thickness-default (integer(0:MAX))

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

5.2.16 print-shell-thickness-supported (1setOf (integer(0:MAX) | rangeOfInteger(0:MAX)))

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

5.2.17 print-speed-default (integer(1:MAX))

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

5.2.18 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.

5.2.19 print-supports-default (type2 keyword)

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

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

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

5.2.21 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.

5.2.22 printer-bed-temperature-default (integer | no-value)

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

5.2.23 printer-bed-temperature-supported (1setOf (integer | rangeOfInteger) | no-value)

This Printer Description attribute lists the supported "printer-bed-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.

5.2.24 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.

517 **5.2.25 printer-chamber-temperature-default (integer | no-value)**

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

520 **5.2.26 printer-chamber-temperature-supported (1setOf (integer | rangeOfInteger) |**
521 **no-value)**

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

525 **5.2.27 printer-fan-speed-default (integer(0:MAX))**

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

527 **5.2.28 printer-fan-speed-supported (boolean)**

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

530 **5.2.29 printer-head-temperature-supported (1setOf (integer | rangeOfInteger))**

531 This Printer Description attribute specifies the supported "printer-head-temperature" values
532 (or ranges of values) in degrees Celsius.

533 **5.2.30 printer-volume-supported (collection)**

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

538 ## 5.3 Printer Status Attributes

539 **5.3.1 printer-bed-temperature-current (integer | no-value)**

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

542 **5.3.2 printer-chamber-temperature-current (integer | no-value)**

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

545 **5.3.3 printer-fan-speed-current (integer(0:100))**

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

5.3.4 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. [Editor's note: Do we need this if we are not specifying material temperature?]

5.4 Other Potential Attributes

Based on existing 3D printer software, the following parameters could also be candidates for standardization:

1. Initial layer thickness in nanometers
2. Initial layer line width in percent
3. Dual extrusion overlap in nanometers
4. Travel speed in nanometers per second
5. Bottom layer speed in nanometers per second
6. Infill speed in nanometers per second
7. Outer shell speed in nanometers per second
8. Inner shell speed in nanometers per second
9. Minimum layer time in seconds or milliseconds

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.

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

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

'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.

'laser-failure': A laser has failed.

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

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

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

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

'motor-failure': A motor has failed.

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

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

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

7. Object Definition Languages (ODLs)

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

7.1 Additive Manufacturing Format (AMF)

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

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

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

603 ## 7.2 Standard Tessellation Language (STL)

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

606 # 8. Internationalization Considerations

607 For interoperability and basic support for multiple languages, conforming implementations
608 MUST support:

609 5. The Universal Character Set (UCS) Transformation Format -- 8 bit (UTF-8)
610 [STD63] encoding of Unicode [UNICODE] [ISO10646]; and
611 6. The Unicode Format for Network Interchange [RFC5198] which requires
612 transmission of well-formed UTF-8 strings and recommends transmission of
613 normalized UTF-8 strings in Normalization Form C (NFC) [UAX15].

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

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

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

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

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

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

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

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

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

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

630 Unicode Character Property Model [UTR23] – character properties

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

632 Unicode Collation Algorithm [UTS10] – sorting

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

634 9. Security Considerations

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

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

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

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

641 9.1 Access Control

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

645 9.2 Physical Safety

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

648 9.3 Material Safety

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

653 9.4 Temperature Control

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

657 10. References

658 [ISO10646] "Information technology -- Universal Coded Character Set (UCS)",
659 ISO/IEC 10646:2011

[ISO52915] "Standard Specification for Additive Manufacturing File Format (AMF) Version 1.1", ISO/ASTM 52915, 2013

[PWG5100.12] M. Sweet, I. McDonald, "IPP Version 2.0, 2.1, and 2.2", PWG 5100.12-YYYY, Month Year, http://ftp.pwg.org/pub/pwg/candidates/cs-ipp20-YYYYMMDD-5100.12.pdf

[PWG5100.14] M. Sweet, I. McDonald, A. Mitchell, J. Hutchings, "IPP Everywhere", PWG 5100.14, January 2013, http://ftp.pwg.org/pub/pwg/candidates/cs-ippeve10-20130128.pdf

[PWG5100.18] M. Sweet, I. McDonald, "IPP Shared Infrastructure Extensions (INFRA)", PWG 5100.18, June 2015, http://ftp.pwg.org/pub/pwg/candidates/cs-ippinfra10-20150619-5100.18.pdf

[RFC2911] T. Hastings, R. Herriot, R. deBry, S. Isaacson, P. Powell, "Internet Printing Protocol/1.1: Model and Semantics", RFC 2911, September 2000, http://tools.ietf.org/html/rfc2911

[RFC3805] R. Bergman, H. Lewis, I. McDonald, "Printer MIB v2", RFC 3805, June 2004, http://tools.ietf.org/html/rfc3805

[RFC3806] R. Bergman, H. Lewis, I. McDonald, "Printer Finishing MIB", RFC 3806, June 2004, http://tools.ietf.org/html/rfc3806

[RFC5198] J. Klensin, M. Padlipsky, "Unicode Format for Network Interchange", RFC 5198, March 2008, http://tools.ietf.org/html/rfc5198

[STD63] F. Yergeau, "UTF-8, a transformation format of ISO 10646", RFC 3629/STD 63, November 2003, http://tools.ietf.org/html/rfc3629

[STLFORMAT] 3D Systems, Inc., "SLC File Specification", 1994

[UAX9] Unicode Consortium, "Unicode Bidirectional Algorithm", UAX#9, June 2014, http://www.unicode.org/reports/tr9/tr9-31.html

[UAX14] Unicode Consortium, "Unicode Line Breaking Algorithm", UAX#14, June 2014, http://www.unicode.org/reports/tr14/tr14-33.html

[UAX15] Unicode Consortium, "Normalization Forms", UAX#15, June 2014, http://www.unicode.org/reports/tr15/tr15-41.html

[UAX29] Unicode Consortium, "Unicode Text Segmentation", UAX#29, June 2014, http://www.unicode.org/reports/tr29/tr29-25.html

[UAX31] Unicode Consortium, “Unicode Identifier and Pattern Syntax”, UAX#31, June 2014, http://www.unicode.org/reports/tr31/tr31-21.html

[UNICODE] Unicode Consortium, "Unicode Standard", Version 7.0.0, June 2014, http://www.unicode.org/versions/Unicode7.0.0/

[UNISECFAQ] Unicode Consortium “Unicode Security FAQ”, November 2013, http://www.unicode.org/faq/security.html

[UTR17] Unicode Consortium “Unicode Character Encoding Model”, UTR#17, November 2008, http://www.unicode.org/reports/tr17/tr17-7.html

[UTR20] Unicode Consortium “Unicode in XML and other Markup Languages”, UTR#20, January 2013, http://www.unicode.org/reports/tr20/tr20-9.html

[UTR23] Unicode Consortium “Unicode Character Property Model”, UTR#23, November 2008, http://www.unicode.org/reports/tr23/tr23-9.html

[UTR33] Unicode Consortium “Unicode Conformance Model”, UTR#33, November 2008, http://www.unicode.org/reports/tr33/tr33-5.html

[UTS10] Unicode Consortium, “Unicode Collation Algorithm”, UTS#10, June 2014, http://www.unicode.org/reports/tr10/tr10-30.html,

[UTS35] Unicode Consortium, “Unicode Locale Data Markup Language”, UTS#35, September 2014, http://www.unicode.org/reports/tr35/tr35-37/tr35.html

[UTS39] Unicode Consortium, “Unicode Security Mechanisms”, UTS#39, September 2014, http://www.unicode.org/reports/tr39/tr39-9.html

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12. Change History

12.1 August 12, 2015

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

12.2 July 29, 2015

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

12.3 April 13, 2015

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

12.4 April 5, 2015

1. Updated front matter to remove IEEE-ISTO boilerplate.
2. Fixed various typos
3. Clarified that SLC files are commonly known as STL files.
4. Clarified that S3G is a binary version of G-code with a standard packet format.
5. Added use case for printing with loaded materials
6. Added use case for multi-material printing on a single material printer.

7. Added use case for monitoring print progress visually with a web cam.
8. Added exception for "skipping" (insufficient material flow/feed)
9. Added exception for adhesion issues
10. Added exception for build plate being full.
11. Added exception for head movement issues.
12. Added figure showing the typical coordinate system.
13. Expanded Job Template and Printer Description details, added comments for discussion.
14. Added new Unicode considerations and references.

12.5 January 23, 2015

Initial revision.

