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-20151029.docx
http://ftp.pwg.org/pub/pwg/ipp/ws/wd-sweet-ipp3d-20151029.pdf

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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, and issue that has plagued 2D printing for years.

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

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

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

204 *SDL*: Selective Deposition Lamination

205 *SL*: Stereo Lithography

206 *USB*: Universal Serial Bus, http://www.usb.org/
207

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.

3.2.8 Print Bed Temperature Out of Range

While printing a 3D object, the print bed temperature goes out of the requested range. 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.

3.2.9 Print Bed Not Clear

When starting to print a 3D object, the Printer detects that the build platform is not empty/clear. 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. The Printer starts printing once the build platform is cleared.

3.3 Out of Scope

The following are considered out of scope for this document:

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

3.4 Design Requirements

The design requirements for this document are:

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

The design recommendations for this document are:

1. Support 3D printing technologies other than FDM

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 standardize. 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

The IPP/1.1 Model and Semantics [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. Figure 1 shows the generalized IPP model. The IPP Server provides the external network interface for IPP Clients, while the Print Service manages and processes Jobs and communicates with the Output Device(s) and their sub-units.

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

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

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

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

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

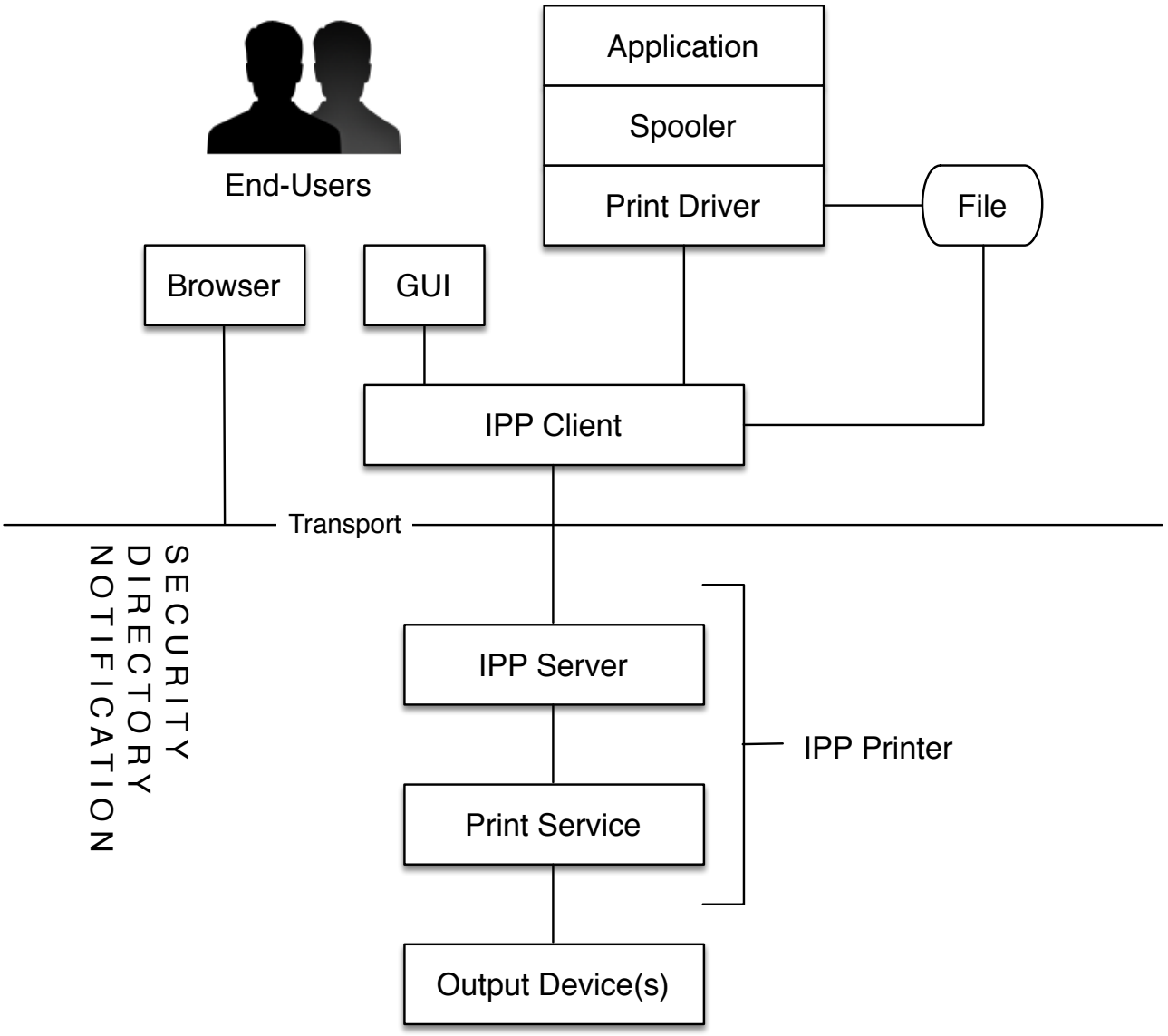


Figure 1 - Generalized IPP Model (RFC 2911)

4.2 3D Printer Subunits

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>

4.2.1 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.

4.2.2 Cameras

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

4.2.3 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.

4.2.4 Fans

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

4.2.5 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.

360 **4.2.6 Lasers**

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

363 **4.2.7 Markers (or Extruders)**

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

367 **4.2.8 Motors**

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

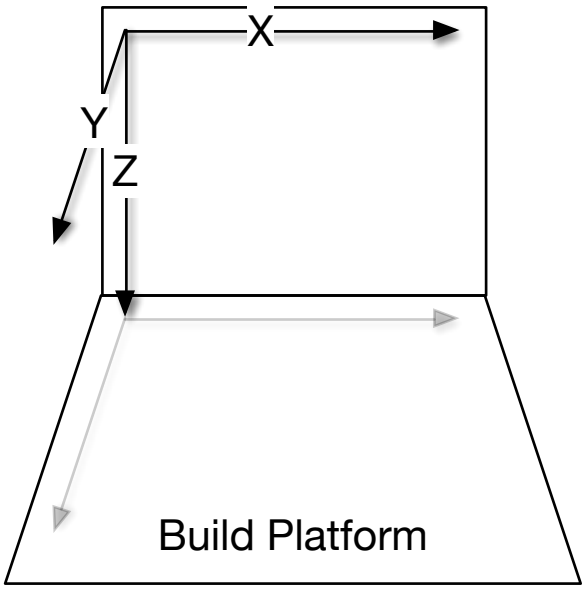
369 **4.2.9 Reservoirs**

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

371 ## 4.3 3D Printer Coordinate System

372 3D printers operate in three dimensions and thus have three axis of movement. Figure 2
373 shows a typical coordinate system where the X axis represents the width of the object, the
374 Y axis represents the depth of the object, and the Z axis represents the height of the
375 object. Note that, depending on the technology used, the Z axis may move in the opposite
376 direction, or the extruder may move independently with a stationary build platform.

377



378

379 **Figure 2 - 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.

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

4.4 Output Intent and Job Processing

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.

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

4.5 Job Spooling

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

4.6 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.

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

5. New Attributes

5.1 Job Template Attributes

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

Table 2 - Job Template Attributes

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

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 5.3.3) Printer Description attributes.

[Discuss proposal for new member attributes to describe material requirements/consumption: material-length-mm (integer(0:MAX)), material-mass-g (integer(0:MAX)), and material-volume-ml (integer(0:MAX))]

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.

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

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

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

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

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

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

5.2 Job Description Attributes

5.2.1 materials-col-actual (1setOf collection)

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

5.3 Printer Description Attributes

5.3.1 materials-col-database (1setOf collection)

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

5.3.2 materials-col-default (1setOf collection)

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

5.3.3 materials-col-ready (1setOf collection)

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

5.3.4 materials-col-supported (1setOf type2 keyword)

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

5.3.5 material-type-supported (1setOf type2 keyword)

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

526 **5.3.6 material-use-supported (1setOf type2 keyword)**

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

528 **5.3.7 print-fill-density-default (integer(0:100))**

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

530 **5.3.8 print-fill-thickness-default (integer(0:MAX))**

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

533 **5.3.9 print-fill-thickness-supported (1setOf (integer(0:MAX) |**
534 **rangeOfInteger(0:MAX)))**

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

537 **5.3.10 print-layer-order (type1 keyword)**

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

540 **5.3.11 print-layer-thickness-default (integer(0:MAX))**

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

543 **5.3.12 print-layer-thickness-supported (1setOf (integer(0:MAX) |**
544 **rangeOfInteger(0:MAX)))**

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

547 **5.3.13 print-rafts-default (type2 keyword)**

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

549 **5.3.14 print-rafts-supported (1setOf type2 keyword)**

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

551 **5.3.15 print-shell-thickness-default (integer(0:MAX))**

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

554 **5.3.16 print-shell-thickness-supported (1setOf (integer(0:MAX) |**
555 **rangeOfInteger(0:MAX)))**

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

558 **5.3.17 print-speed-default (integer(1:MAX))**

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

561 **5.3.18 print-speed-supported (1setOf (integer(1:MAX) | rangeOfInteger(1:MAX)))**

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

564 **5.3.19 print-supports-default (type2 keyword)**

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

566 **5.3.20 print-supports-supported (1setOf type2 keyword)**

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

568 **5.3.21 printer-accuracy-supported (collection)**

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

572 **5.3.22 printer-bed-temperature-default (integer | no-value)**

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

575 **5.3.23 printer-bed-temperature-supported (1setOf (integer | rangeOfInteger) | no-**
576 **value)**

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

580 **5.3.24 printer-camera-image-uri (1setOf uri)**

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

585 **5.3.25 printer-chamber-temperature-default (integer | no-value)**

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

588 **5.3.26 printer-chamber-temperature-supported (1setOf (integer | rangeOfInteger) |**
589 **no-value)**

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

593 **5.3.27 printer-fan-speed-default (integer(0:MAX))**

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

595 **5.3.28 printer-fan-speed-supported (boolean)**

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

598 **5.3.29 printer-head-temperature-supported (1setOf (integer | rangeOfInteger))**

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

601 **5.3.30 printer-volume-supported (collection)**

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

606 5.4 Printer Status Attributes

607 **5.4.1 printer-bed-temperature-current (integer | no-value)**

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

610 **5.4.2 printer-chamber-temperature-current (integer | no-value)**

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

613 **5.4.3 printer-fan-speed-current (integer(0:100))**

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

615 **5.4.4 printer-head-temperature-current (1setOf (integer | no-value))**

616 This Printer Status attribute provides the current extruder head temperatures in degrees
617 Celsius. The 'no-value' value is returned when the extruder head is not temperature
618 controlled. [Editor's note: Do we need this if we are not specifying material temperature?]

619 ## 5.5 Other Potential Attributes

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

622 1. Initial layer thickness in nanometers
623 2. Initial layer line width in percent
624 3. Dual extrusion overlap in nanometers
625 4. Travel speed in nanometers per second
626 5. Bottom layer speed in nanometers per second
627 6. Infill speed in nanometers per second
628 7. Outer shell speed in nanometers per second
629 8. Inner shell speed in nanometers per second
630 9. Minimum layer time in seconds or milliseconds

631 # 6. New Values for Existing Attributes

632 ## 6.1 ipp-features-supported (1setOf type2 keyword)

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

634 ## 6.2 printer-state-reasons (1setOf type2 keyword)

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

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

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

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

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

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

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

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

643 '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.

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

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 3D Manufacturing Format (3MF)

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

The suggested (but not registered) MIME media type is "model/3mf".

7.2 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'.

7.3 Standard Tessellation Language (STL)

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

8. Internationalization Considerations

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

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

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

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

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

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

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

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

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

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

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

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

Unicode Character Property Model [UTR23] – character properties

Unicode Conformance Model [UTR33] – Unicode conformance basis+

Unicode Collation Algorithm [UTS10] – sorting

Unicode Locale Data Markup Language [UTS35] – locale databases

9. Security Considerations

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

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

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

Unicode Security FAQ [UNISECFAQ] – common Unicode security issues

9.1 Access Control

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

9.2 Physical Safety

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

9.3 Material Safety

Printers MUST restrict usage and combination of materials to those that can be safely printed. Access controls (section 9.1) MAY be used to allow authorized users to

experiment with untested materials or combinations, but only when such materials or combinations can reasonably be expected to not pose a safety risk.

9.4 Temperature Control

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

10. References

[3MF] "3D Manufacturing Format Core Specification & Reference Guide v1.0", http://www.3mf.io/wp-content/uploads/2015/04/3MFcoreSpec_1.0.1.pdf

[ISO10646] "Information technology -- Universal Coded Character Set (UCS)", 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-ippeve10-20130128-5100.14.pdf

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[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

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12. Change History

12.1 October 29, 2015

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

12.2 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.

12.3 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.

12.4 April 13, 2015

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

12.5 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.

12.6 January 23, 2015

Initial revision.

