



The Printer Working Group

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IPP 3D Printing Extensions v1.1 (3D)

Status: Approved

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

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

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1. Introduction

This specification 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 primary focus of this specification is on popular Fused Deposition Modeling (FDM) devices that melt and extrude filaments of ABS, PLA, or other materials 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.

Discovery of IPP 3D Printers is based on the methods defined in IPP Everywhere [PWG5100.14].

In order to promote adoption and interoperability, this specification requires support for a common Object Definition Language (ODL). Recommendations and guidance for other ODLs are also provided, including material mapping strategies, in order to provide the greatest flexibility while ensuring consistency and interoperability for future formats.

This specification 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.

Sample code implementing this specification has been published in the ISTO-PWG IPP Sample Code Repository [IPPSAMPLE].

2. Terminology

2.1 Conformance Terminology

Capitalized terms, such as MUST, MUST NOT, RECOMMENDED, REQUIRED, SHOULD, SHOULD NOT, MAY, and OPTIONAL, have special meaning relating to conformance as defined in Key words for use in RFCs to Indicate Requirement Levels [BCP14]. The term CONDITIONALLY REQUIRED is additionally defined for a conformance requirement that applies when a specified condition is true.

2.2 Printing Terminology

Normative definitions and semantics of printing terms are imported from IETF Printer MIB v2 [RFC3805], IETF Finisher MIB [RFC3806], and IETF Internet Printing Protocol/1.1: Model and Semantics [STD92].

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

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

Logical Device: a print server, software service, or gateway that processes Jobs and either forwards or stores the processed Job or uses one or more Physical Devices to render output.

Output Device: a single Logical or Physical Device

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

2.3 Protocol Role Terminology

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

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

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

2.4 3D Printing Terminology

Additive Manufacturing: A 3D printing process where material is progressively added to produce the final output, as opposed to Subtractive Manufacturing and Formative Manufacturing technologies.

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, sometimes also called vat photopolymerization.

Formative Manufacturing: Traditional casting, moulding, or forming processes used for mass production, for example injection moulding of plastic parts.

Fused Deposition Modeling: A 3D printing process that extrudes a molten material to draw layers, sometimes also called material extrusion.

Laser Sintering: A 3D printing process that uses a laser to melt and fuse layers of powdered materials, sometimes also called directed energy deposition or powder bed fusion.

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, sometimes also called sheet lamination.

Slicing: The process of converting three-dimensional geometry into two-dimensional planes that can be layered to produce an equivalent three-dimensional object.

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.

2.5 Other Terminology

Directory Service: A Service providing query and enumeration of information using names or other identifiers.

Discovery: Finding Printers by querying or browsing local network segments or Enumeration of Directory or Name Services.

Enumeration: Listing Printers that are registered with a Directory or other Service.

Service: Software providing access to physical, logical, or virtual resources and (typically) processing of queued Jobs.

2.6 Acronyms and Organizations

3D PDF Consortium: <http://www.3dpdfconsortium.org/>

3MF Consortium: 3D Manufacturing Format Consortium, <http://www.3mf.io/>

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 Version 2.0, 2.1, and 2.2 [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;
5. The Universal 3D File Format [ECMA363] defines a binary format for 3D objects embedded in PDF files;
6. Document management -- 3D use of Product Representation Compact (PRC) format -- Part 1: PRC 10001 [ISO14739] defines a binary format for 3D objects embedded in PDF files; and
7. Document management — Portable document format — Part 1: PDF 1.7 [ISO32000] defines a binary file format that supports embedded 3D objects with one or more materials.

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 Print a Tool

Jane wants to print an adjustable wrench. Because the wrench contains interlocking pieces that must be printed accurately for it to work properly, Jane specifies the required dimensional accuracy with the software on her Client device prior to submitting the print. The Printer then validates that it can support the required accuracy before accepting the Job.

3.1.5 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 Build Platform Temperature Out of Range

While printing a 3D object, the Build Platform 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 Build Platform 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;
2. Support for Subtractive Manufacturing technologies such as CNC milling machines; and

3. Support for industrial and/or medical printing technologies.

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 consumer desktop 3D Printers and print services, including color, fill, purpose, thickness, and type;
2. Define attributes and values to describe consumer desktop 3D Printer and print service capabilities and state;
3. Define attributes and values to describe printing features and/or constraints including dimensional accuracy and generation of rafts and supports;
4. Define attributes and values to describe the objects being printed, including UUID, bounding box, and offsets;
5. Define attributes to provide a receipt of the printed Job;
6. Define discovery mechanisms for 3D Printers;
7. Define security requirements necessary to support privacy and device safety;
8. Identify secure transport mechanisms for 3D Printers; and
9. Define sections to register all attributes, values, operations, and service types with IANA.

The design recommendations for this document are:

1. Support 3D printing technologies other than FDM

4. 3D Print Service Model

The IPP/1.1 Model and Semantics [STD92], 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 (attribute 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 (Get-Notifications operation).

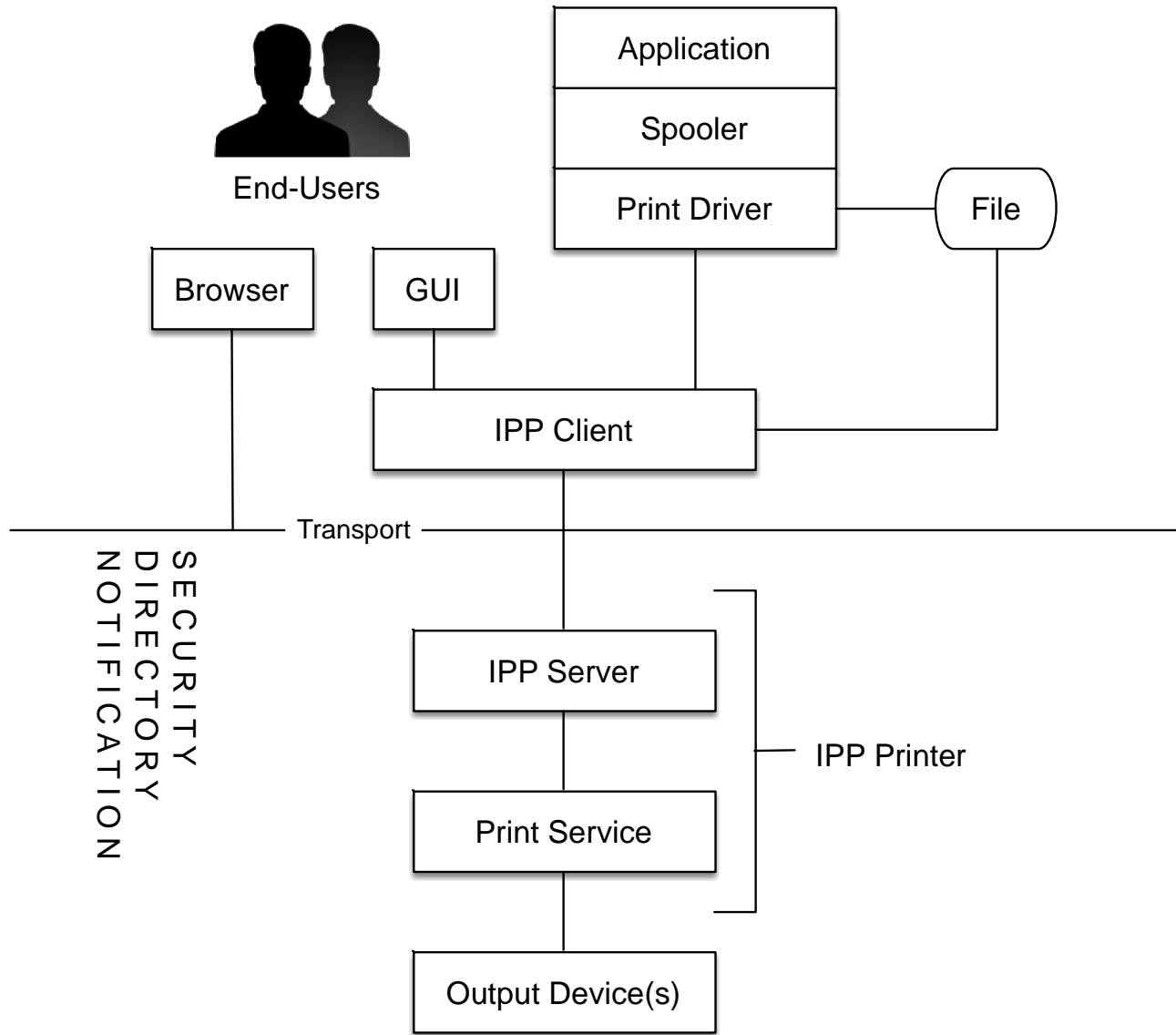


Figure 1 - Generalized IPP Model (RFC 8011)

4.1 3D Print Service

3D printing uses a variation of the traditional Print service that maintains state and capability information specific to 3D printing. The 3D Print service supports all of the same operations of the Print service described in [STD92] except for the Print-Job and Print-URI operations which are compound requests that are not used in newer IPP services. Similarly, the 3D Print service uses a superset of the Print service attributes except where such attributes are not applicable, for example the "media" attributes for a 3D printer that does not use media sheets. Attributes specific to the 3D Print Service are defined in section 8.

4.2 3D Printer Subunits

Table 1 lists the subunits of 3D printers for different technologies. Not all subunits are exposed by Printers due to hardware or implementation limitations.

Table 1 - 3D Printer Subunits

2D Subunit	3D Subunit(s)	Technology	Reference
Finishing Devices	Trimmers	All	RFC 3806
Input Trays/Rolls	Input Trays/Rolls	SDL	RFC 3805
Marker Supplies	Filament, Granules, Liquids, Powders, Reservoirs	All	RFC 3805
Markers	Extruders, Lamps, Lasers, Projectors	All	RFC 3805
Media Path	Build Platforms, Chambers	Many	RFC 3805

4.2.1 Finishing Devices

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

4.2.2 Input Trays/Rolls

Input Trays/Rolls provide sheet or roll media for printing.

4.2.3 Marker Supplies

Marker Supplies include Filament, Granules, Liquids, Powders, and Reservoirs that are used to supply the Marker(s) with material for printing.

4.2.4 Markers

Markers can print an image on sheets of paper (SDL), melt and extrude material onto the Build Platform or previous layer, project an inverse image on the surface of a liquid material (DLP), or perform any other action to print an object.

Markers include fans, lasers, lamps, motors, and other components that are sometimes manually controlled by Printer-specific software but are not exposed by the IPP model.

4.2.5 Media Paths

Media Paths include traditional Media Sheet paths (SDL) as well as Build Platforms and Chambers. 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.

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 3D Printer Coordinate System

3D printers operate in three dimensions and thus have three axis of movement. For the purposes of IPP, the build volume is defined as a rectangular prism (Figure 2) with the X axis representing the width, the Y axis representing the depth, and the Z axis representing the height. The origin is implementation-specific.

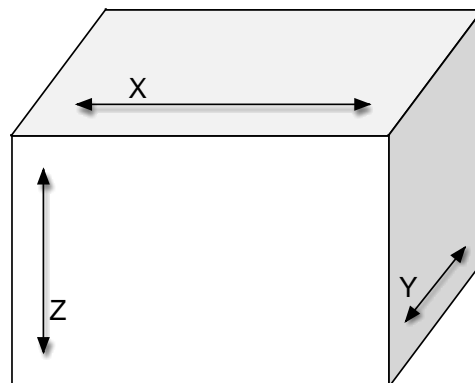


Figure 2 - 3D Build Volume

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 preferences and quality, 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 (layering) 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 Multiple Document Jobs

Printers that support Jobs with multiple Documents SHOULD be capable of printing the objects defined in those Documents side-by-side. For example, if a Client submits two Documents, of a cat and a dog respectively, the Printer SHOULD be able to print the cat and dog at the same time as long as they fit within the build volume.

The "multiple-object-handling" (section 8.1.4) Job Template attribute controls whether the Printer performs this optimization.

4.7 Cloud-Based Printing

Cloud-based printing is 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 specification and can be considered a part of provisioning the Cloud Service.

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

5. Discovery Protocols

Clients and Printers MUST support DNS-SD based Discovery. Clients and Printers MAY support other Discovery protocols such as LDAP.

5.1 DNS Service Discovery (DNS-SD)

DNS Service Discovery [RFC6762] uses service (SRV) records and traditional unicast and multicast DNS (mDNS) [RFC6763] queries. Printers MUST support mDNS and MAY support dynamic DNS updates via Dynamic Updates in the Domain Name System (DNS UPDATE) [RFC2136] and other mechanisms.

5.1.1 Service Instance Name

Printers MUST NOT use a service instance name containing a unique identifier by default. A unique identifier MAY be added to the instance if there is a name collision.

The domain portion of the service instance name MUST BE "local." for mDNS.

5.1.2 Service Type

Printers MUST advertise the "_ippes-3d._tcp" (IPPS 3D Print) service over DNS-SD.

5.1.3 TXT Record

Table 2 lists the TXT record key/value pairs for IPPS 3D Print services. The TXT record associated with the service MUST include the "adminurl" and "UUID" keys and MUST include the "note" and "rp" keys when they are not the default values.

Table 2 - IPPS 3D Print Service TXT Record Keys

Key	Description	Default Value
adminurl	The 'https' URL for the Printer's embedded web server.	None
note	The value of the "printer-location" Printer Description attribute.	""
pdl	The values of the "document-formats-supported" Printer Description attribute.	"model/3mf"
rp	The resource path for this service instance without the leading "/".	"ipp/print3d"

ty	The value of the "printer-make-and-model" Printer Description attribute.	""
UUID	The value of the "printer-uuid" Printer Status attribute without the leading 'urn:uuid:'.	None

5.2 LDAP Discovery

LDAP Discover uses Lightweight Directory Access Protocol v3 [RFC4510]. A single class for 3D Print services is used. The schema defined in this document is based on the LDAP Schema for Print Services [RFC7612] used for 2D Printer services.

5.2.1 printerIPPS3D Class

This auxiliary class defines 3D Printer information. It is used to extend the existing "printerService" structural class with 3D-specific Printer information.

```
( 1.3.18.0.2.24.46.2.1
  NAME 'printerIPPS3D'
  DESC 'Internet Printing Protocol (IPP) 3D Print Service information.'
  AUXILIARY
  SUP top
  MAY ( printer-ipp-versions-supported $
        printer-ipp-features-supported $
        printer-multiple-document-jobs-supported )
)
```

6. Protocol Binding

Printers and Clients MUST support IPP/2.0 as defined in IPP 2.0, 2.1, and 2.2 [PWG5100.12]. While this specification defines an IPP binding, the same set of Semantic Elements can be applied to any protocol that conforms to the PWG Semantic Model.

6.1 Transport and Resource Path

Printers MUST support and use the IPP over HTTPS Transport Binding and 'ipps' URI Scheme [RFC7472] for network-connected Clients and/or the The IPP URL Scheme [RFC3510] and IPP-USB [IPP-USB] for USB-connected Clients. Printers MUST NOT support the "ipp" URI scheme for network-connected Clients since it does not satisfy the security requirements defined in section 12.

Printers MUST use a URI resource path of "/ipp/print3d" or "/ipp/print3d/NAME" where "NAME" identifies a specific instance of a 3D Print service.

6.2 HTTP Features

In addition to the IPP over HTTP conformance requirements defined in section 7.3 of IPP 2.0, 2.1, and 2.2 [PWG5100.12], Printers MUST support the following additional HTTP headers and status codes defined in Hypertext Transfer Protocol -- HTTP/1.1 [RFC7230].

6.2.1 Host

Printers MUST validate the Host request header and SHOULD use the Host value in generated URIs.

6.2.2 If-Modified-Since, Last-Modified, and 304 Not Modified

Printers MUST support the If-Modified-Since request header (section 3.3 [RFC7232]), the corresponding response status ("304 Not Modified", section 4.1 [RFC7232]), and the Last-Modified response header (section 2.2 [RFC7232]).

The If-Modified-Since request header allows a Client to efficiently determine whether a particular resource file (icon, camera image, localization file, etc.) has been updated since the last time the Client requested it.

6.2.3 Cache-Control

Printers and Clients MUST conform to the caching semantics defined in section 5.2 [RFC7234]. Typically, most resource files provided by a Printer in a GET response will be cacheable but IPP responses in a POST response are not. Therefore, Printers MAY provide

a Cache-Control header in GET responses with an appropriate "max-age" value and MUST provide a Cache-Control header in IPP POST responses with the value "no-cache".

6.3 IPP Operations

Table 3 lists the REQUIRED operations for a Printer. The Create-Job and Send-Document operations are required in order to support reliable Job management (e.g., cancellation) during print Job submission, but Printers are not required to support multiple document Jobs.

Table 3 - IPP 3D REQUIRED Operations

Code	Operation Name	Reference
0x0004	Validate-Job	RFC 8011
0x0005	Create-Job	RFC 8011
0x0006	Send-Document	RFC 8011
0x0008	Cancel-Job	RFC 8011
0x0009	Get-Job-Attributes	RFC 8011
0x000A	Get-Jobs	RFC 8011
0x000B	Get-Printer-Attributes	RFC 8011
0x0039	Cancel-My-Jobs	PWG 5100.11
0x003B	Close-Job	PWG 5100.11
0x003C	Identify-Printer	PWG 5100.13

6.4 IPP Operation Attributes

Table 4 lists the REQUIRED operation attributes for a Printer.

Table 4 - IPP 3D REQUIRED Operation Attributes

Attribute	Reference
compression	RFC 8011
document-format	RFC 8011
document-name	RFC 8011, PWG 5100.5
first-index	PWG 5100.13

identify-actions	PWG 5100.13
ipp-attribute-fidelity	RFC 8011
job-ids	PWG 5100.11
job-mandatory-attributes	PWG 5100.7
job-name	RFC 8011
last-document	RFC 8011
limit	RFC 8011
requesting-user-name	RFC 8011
requesting-user-uri	PWG 5100.13
which-jobs	RFC 8011, PWG 5100.11

6.5 IPP Printer Description Attributes

Table 5 lists the REQUIRED Printer Description attributes for a Printer.

Table 5 - IPP 3D REQUIRED Printer Description Attributes

Attribute	Reference
accuracy-units-supported	Section 8.3.1
charset-configured	RFC 8011
charset-supported	RFC 8011
color-supported	RFC 8011
compression-supported	RFC 8011
document-format-default	RFC 8011
document-format-supported	RFC 8011
generated-natural-language-supported	RFC 8011
identify-actions-default	PWG 5100.13
identify-actions-supported	PWG 5100.13
ipp-features-supported	PWG 5100.13

Attribute	Reference
ipp-versions-supported	RFC 8011
job-creation-attributes-supported	PWG 5100.11
job-ids-supported	PWG 5100.11
material-diameter-supported (note 2)	Section 8.3.7
material-purpose-supported	Section 8.3.9
material-rate-supported	Section 8.3.10
material-rate-units-supported	Section 8.3.11
material-shell-thickness-supported	Section 8.3.12
material-temperature-supported (note 3)	Section 8.3.12
material-type-supported	Section 8.3.14
materials-col-default	Section 8.3.16
materials-col-ready	Section 8.3.17
materials-col-supported	Section 8.3.18
max-materials-col-supported	Section 8.3.19
multiple-document-jobs-supported	RFC 8011
multiple-object-handling-default	Section 8.3.20
multiple-object-handling-supported	Section 8.3.21
multiple-operation-timeout	RFC 8011
multiple-operation-timeout-action	PWG 5100.13
natural-language-configured	RFC 8011
operations-supported	RFC 8011
platform-temperature-default (note 4)	Section 8.3.24
platform-temperature-supported (note 4)	Section 8.3.25
print-accuracy-default	Section 8.3.26
print-accuracy-supported	Section 8.3.27
print-base-default	Section 8.3.28
print-base-supported	Section 8.3.29

Attribute	Reference
print-objects-supported	Section 8.3.30
print-quality-default	RFC 8011
print-quality-supported	RFC 8011
print-supports-default	Section 8.3.31
print-supports-supported	Section 8.3.32
printer-geo-location	PWG 5100.13
printer-get-attributes-supported	PWG 5100.13
printer-icons (note 1)	PWG 5100.13
printer-info	RFC 8011
printer-location	RFC 8011
printer-make-and-model	RFC 8011
printer-more-info	RFC 8011
printer-name	RFC 8011
printer-organization	PWG 5100.13
printer-organizational-unit	PWG 5100.13
printer-volume-supported	Section 8.3.33
printer-xri-supported (note 1)	RFC 3380
which-jobs-supported	PWG 5100.11

Note 1: URIs SHOULD use Host value from HTTP header (section 6.2.1) and MUST NOT use link-local addresses (section 8.4 of [PWG5100.14]).

Note 2: REQUIRED for Printers that use filament-based materials.

Note 3: REQUIRED for Printers that control the material temperature during printing.

Note 4: REQUIRED for Printers that have a temperature-controlled Build Platform.

6.6 IPP Printer Status Attributes

Table 6 lists the REQUIRED Printer Status attributes for a Printer.

Table 6 - IPP 3D REQUIRED Printer Status Attributes

Attribute	Reference
printer-camera-image-uri (notes 1, 2)	Section 8.4.1
printer-config-change-date-time	PWG 5100.13
printer-config-change-time	PWG 5100.13
printer-is-accepting-jobs	RFC 8011
printer-state	RFC 8011
printer-state-change-date-time	RFC 3995
printer-state-change-time	RFC 3995
printer-state-message	RFC 8011
printer-state-reasons	RFC 8011
printer-up-time	RFC 8011
printer-uri-supported (note 1)	RFC 8011
printer-uuid	PWG 5100.13
queued-job-count	RFC 8011
uri-authentication-supported	RFC 8011
uri-security-supported	RFC 8011
xri-authentication-supported	RFC 3380
xri-security-supported	RFC 3380
xri-uri-scheme-supported	RFC 3380

Note 1: URIs SHOULD use Host value from HTTP header (section 6.2.1) and MUST NOT use link-local addresses (section 8.4 of [PWG5100.14]).

Note 2: REQUIRED for Printers that have one or more cameras.

6.7 IPP Job Template Attributes

Table 7 lists the REQUIRED Job Template attributes for a Printer.

Table 7 - IPP 3D REQUIRED Job Template Attributes

Attribute	Reference
materials-col	Section 8.1.1
multiple-document-handling	RFC 8011
multiple-object-handling (note 1)	Section 8.1.4
platform-temperature (note 2)	Section 8.1.5
print-accuracy	Section 8.1.6
print-base	Section 8.1.7
print-objects (note 1)	Section 8.1.8
print-quality	RFC 8011
print-supports	Section 8.1.9

Note 1: REQUIRED for Printers that support the 'application/pdf' document format.

Note 2: REQUIRED for Printers that have a temperature-controlled Build Platform.

6.8 IPP Job Description Attributes

Table 8 lists the REQUIRED Job Description attributes for a Printer.

Table 8 - IPP 3D REQUIRED Job Description Attributes

Attribute	Source
job-name	RFC 8011

6.9 IPP Job Status Attributes

Table 8 lists the REQUIRED Job Status attributes for a Printer.

Table 9 - IPP 3D REQUIRED Job Status Attributes

Attribute	Source
compression-supplied	PWG 5100.7
date-time-at-completed	RFC 8011
date-time-at-creation	RFC 8011
date-time-at-processing	RFC 8011
document-format-supplied	PWG 5100.7
document-name-supplied	PWG 5100.7
job-id	RFC 8011
job-originating-user-name	RFC 8011
job-printer-up-time	RFC 8011
job-printer-uri	RFC 8011
job-state	RFC 8011
job-state-message	RFC 8011
job-state-reasons	RFC 8011
job-uri	RFC 8011
job-uuid	PWG 5100.13
materials-col-actual	Section 8.2.3
multiple-object-handling-actual (note 1)	Section 8.2.4
platform-temperature-actual (note 2)	Section 8.2.6
print-accuracy-actual	Section 8.2.7
print-base-actual	Section 8.2.8
print-objects-actual (note 1)	Section 8.2.9
print-supports-actual	Section 8.2.10
time-at-completed	RFC 8011
time-at-creation	RFC 8011
time-at-processing	RFC 8011

Note 1: REQUIRED for Printers that support the 'application/pdf' document format.

Note 2: REQUIRED for Printers that have a temperature-controlled Build Platform.

6.9.1 job-id (integer)

The REQUIRED "job-id" Job Description attribute contains the ID of the Job. In order to support reliable job submission and management, Printers MUST NOT reuse "job-id" values since the last power cycle of the Printer and SHOULD NOT reuse "job-id" values for the life of the Printer as described in section 3.1.2.3.9 of the Internet Printing Protocol/1.1: Implementer's Guide [RFC3196].

6.9.2 job-uri (uri)

The REQUIRED "job-uri" Job Description attribute contains the URI of the Job. In order to support reliable job submission and management, Printers MUST NOT reuse "job-uri" values since the Printer was last powered up and SHOULD NOT reuse "job-uri" values for the life of the Printer as described in section 3.1.2.3.9 of the Internet Printing Protocol/1.1: Implementer's Guide [RFC3196]. In addition, the "job-uri" value SHOULD be derived from the "job-id" value as described in the IPP URL Scheme [RFC3510].

7. Document Formats

Printers that support Slicing MUST support Documents conforming to the 3MF [3MF] ("model/3mf") format and SHOULD support Documents conforming to the PDF [ISO32000] ("application/pdf") format containing U3D [U3D] or PRC [PRC] content. Printers that do not support Slicing SHOULD support Documents conforming to a layered format such as PWG Safe G-Code [PWGGCODE] and/or the 3MF Slice Extension [3MF-SLICE].

8. New Attributes

8.1 Job Template Attributes

Table 10 lists the Job Template attributes and their corresponding “–default” and “-supported” attributes.

Table 10 - IPP 3D Job Template Attributes

Job Template	Printer: Default	Printer: Supported
chamber-humidity (integer no-value)	chamber-humidity-default (integer no-value)	chamber-humidity-supported (boolean)
chamber-temperature (integer no-value)	chamber-temperature-default (integer no-value)	chamber-temperature-supported (1setOf (integer rangeOfInteger) no-value)
materials-col (collection)	materials-col-default (1setOf collection)	materials-col-database (1setOf collection) materials-col-ready (1setOf collection) materials-col-supported (1setOf type2 keyword)
multiple-object-handling (type2 keyword)	multiple-object-handling-default (type2 keyword)	multiple-object-handling-supported (1setOf type2 keyword)
platform-temperature (integer no-value)	platform-temperature-default (integer no-value)	platform-temperature-supported (1setOf (integer rangeOfInteger) no-value)
print-accuracy (collection)	print-accuracy-default (collection)	accuracy-units-supported (1setOf type2 keyword) print-accuracy-supported (collection)
print-base (type2 keyword)	print-base-default (type2 keyword)	print-base-supported (1setOf type2 keyword)
print-objects (1setOf collection)	N/A	print-objects-supported (boolean)

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

8.1.1 chamber-humidity (integer(0:100) | no-value)

This Job Template attribute specifies the desired relative humidity of the build chamber as a percentage. Printers that support humidity control SHOULD support this attribute.

8.1.2 chamber-temperature (integer(-273:MAX) | no-value)

This Job Template attribute specifies the desired temperature of the build chamber in degrees Celsius. Printers that support a temperature-controlled build chamber SHOULD support this attribute.

8.1.3 materials-col (1setOf collection)

This REQUIRED 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 Printer advertises which "materials-col" member attributes are supported in the "materials-col-supported" (section 8.3.18) Printer Description attribute. The Printer lists only those member attributes that are applicable to the technology being used for printing.

The Client typically supplies "materials-col" values matching those returned in the "materials-col-database" (section 8.3.1) or "materials-col-ready" (section 8.3.17) Printer Description attributes, although specifying the "material-name" or "material-key" member attribute from either of these Printer Description attributes is enough to specify the default values for the named material. Table 11 lists the member attributes.

Table 11 - "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-diameter-tolerance	N/A

material-fill-density	N/A
material-key	materials-col-database materials-col-ready
material-name	materials-col-database materials-col-ready
material-nozzle-diameter	material-nozzle-diameter-supported
material-purpose	material-purpose-supported
material-rate	material-rate-supported
material-rate-units	material-rate-units-supported
material-retraction	materials-col-supported
material-shell-thickness	material-shell-thickness-supported
material-temperate	material-temperature-supported
material-type	material-type-supported

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

This RECOMMENDED 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).

8.1.3.2 material-amount-units (type2 keyword)

This RECOMMENDED 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.

'ml': Value is volume in milliliters.

'mm': Value is length in millimeters.

8.1.3.3 material-color (type2 keyword)

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

8.1.3.4 material-diameter (integer(0:MAX))

This CONDITIONALLY REQUIRED member attribute provides the diameter of the filament in nanometers, with the value 0 being used for diameters less than 0.000001mm. Printers that use filament materials MUST support this member attribute.

8.1.3.5 material-diameter-tolerance (integer(0:MAX))

This member attribute provides a tolerance for the "material-diameter" value in nanometers, with the value 0 being used for tolerances less than 0.000001mm.

8.1.3.6 material-fill-density (integer(0:100))

This REQUIRED member attribute specifies the desired density of filled interior regions in percent.

8.1.3.7 material-key (keyword)

This REQUIRED 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.

8.1.3.8 material-name (name(MAX))

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

8.1.3.9 material-nozzle-diameter (integer(0:MAX))

This member attribute provides the diameter of the extruder nozzle in nanometers, with the value 0 being used for diameters less than 0.000001mm. Printers that use filament materials SHOULD support this member attribute.

8.1.3.10 material-purpose (1setOf type2 keyword)

This REQUIRED 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.

'base': The material will be used to print a brim, raft, or skirt under/around the printed object.

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

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

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

8.1.3.12 material-rate-units (type2 keyword)

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

'mg_sec ': Value is milligrams per second.

'ml_sec ': Value is milliliters per second.

'mm_sec ': Value is millimeters per second.

8.1.3.13 material-retraction (boolean)

This member attribute specifies whether filament retraction is used for this material. Printers that use filament materials SHOULD support this member attribute.

8.1.3.14 material-shell-thickness (integer(0:MAX))

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

8.1.3.15 material-temperature (integer(-273:MAX) | rangeOfInteger(-273:MAX))

This CONDITIONALLY REQUIRED member attribute specifies the printing temperature (or range of temperatures) for the material in degrees Celsius. Printers that control the temperature of materials MUST support this attribute.

8.1.3.16 material-type (type2 keyword | name(MAX))

This REQUIRED member attribute specifies the type of material. Keyword values are general names for materials (sometimes qualified) and are localized using the message catalog specified by the "printer-strings-uri" Printer Description attribute [PWG5100.13]. Name values are vendor or site specific human readable (already localized) strings. Keyword values include:

'abs': Acrylonitrile Butadiene Styrene (ABS).

'abs-carbon-fiber': ABS reinforced with carbon fibers.

'abs-carbon-nanotube': ABS reinforced with carbon nanotubes.

'chocolate': Chocolate.

'gold': Gold (metal).

'nylon': Nylon.

'pet': Polyethylene terephthalate (PET).

'photopolymer': Photopolymer (liquid) resin.

'pla': Polylactic Acid (PLA).

'pla-conductive': Conductive PLA.

'pla-dissolvable': Dissolvable PLA.

'pla-flexible': Flexible PLA.

'pla-magnetic': PLA with embedded iron particles.

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

'pla-stone': PLA with embedded stone chips.

'pla-wood': PLA with embedded wood fibers.

'polycarbonate': Polycarbonate.

'silver': Silver (metal).

'titanium': Titanium (metal).

'wax': Wax.

Keyword values for materials that are defined by other standards organizations use a format consisting of the organization abbreviation, the standard number, a hyphen ("-"), and the material identifier. In order to conform to the syntax for keyword values (section 5.1.4 of [STD92]), all letters are converted to lowercase (with any diacritical marks removed), ASCII digits, hyphens ("-"), underscores ("_") and periods (".") are preserved, spaces are replaced with the hyphen ("-"), and slashes ("/") are replaced with the underscore ("_"). Any other

characters are removed. For example, "7050 Aluminum" as defined in ASTM B247M would have a keyword value of 'astmb247m-a97050'.

8.1.4 multiple-object-handling (type2 keyword)

This CONDITIONALLY REQUIRED Job Template attribute specifies how multiple objects are printed, including those within a single Document, across multiple Documents, and/or copies that are produced. Printers that support the 'application/pdf' Document format MUST support this attribute. Values include:

'auto': Automatically determine the best way to print multiple objects in a Job.

'best-fit': Fit as many objects as possible within the build volume.

'best-quality': Optimize the number of objects for print quality.

'best-speed': Optimize the number of objects for print speed.

'one-at-a-time': Print one object at a time.

8.1.5 platform-temperature (integer(-273:MAX))

This CONDITIONALLY REQUIRED Job Template attribute specifies the desired temperature of the Build Platform in degrees Celsius. Printers that have a temperature-controlled Build Platform MUST support this attribute.

8.1.6 print-accuracy (collection)

This REQUIRED Job Template attribute specifies the requested general positioning and feature accuracy for the Job. Table 12 lists the REQUIRED member attributes.

When enforcing attribute fidelity ("ipp-attribute-fidelity" with a value of 'true'), Printers only reject "print-accuracy" values that are smaller than the "print-accuracy-supported" (section 8.3.27) value.

Table 12 - REQUIRED "print-accuracy" Member Attributes

Member Attribute	Printer: Supported Values
accuracy-units (type2 keyword)	accuracy-units-supported (1setOf type2 keyword)
x-accuracy (integer(0:MAX))	N/A
y-accuracy (integer(0:MAX))	N/A

z-accuracy (integer(0:MAX))	N/A
-----------------------------	-----

8.1.6.1 accuracy-units (type2 keyword)

This member attribute specifies the units for the "x-accuracy", "y-accuracy", and "z-accuracy" member attribute values. Keyword values include:

'mm': Accuracy numbers are in millimeters.

'um': Accuracy numbers are in micrometers.

'nm': Accuracy numbers are in nanometers.

8.1.6.2 x-accuracy (integer(0:MAX))

This REQUIRED member attribute specifies the X axis accuracy in the units specified by the "accuracy-units" member attribute. The value 0 specifies an accuracy better (smaller) than 1 unit.

8.1.6.3 y-accuracy (integer(0:MAX))

This REQUIRED member attribute specifies the Y axis accuracy in the units specified by the "accuracy-units" member attribute. The value 0 specifies an accuracy better (smaller) than 1 unit.

8.1.6.4 z-accuracy (integer(0:MAX))

This REQUIRED member attribute specifies the Z axis accuracy in the units specified by the "accuracy-units" member attribute. The value 0 specifies an accuracy better (smaller) than 1 unit.

8.1.7 print-base (type2 keyword)

This REQUIRED 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.

8.1.8 print-objects (1setOf collection)

This CONDITIONALLY REQUIRED Job Template attribute specifies the objects to be printed within the Documents. Printers that support the 'application/pdf' Document format MUST support this attribute. Table 13 lists the REQUIRED member attributes.

If not specified in a Job Creation request, the Printer MUST print all objects in each Document. There is no "print-objects-default" Printer Description attribute.

Table 13 - REQUIRED "print-objects" Member Attributes

Member Attribute	Sub-Member Attributes
document-number (integer(1:MAX))	N/A
object-offset (collection)	x-offset (integer(0:MAX))
	y-offset (integer(0:MAX))
	z-offset (integer(0:MAX))
object-size (collection)	x-dimension (integer(1:MAX))
	y-dimension (integer(1:MAX))
	z-dimension (integer(1:MAX))
object-uuid (uri)	N/A

8.1.8.1 document-number (integer(1:MAX))

This member attribute specifies the numbered document containing the object. The first document is number 1, the second document is 2, etc.

8.1.8.2 object-offset (collection)

This member attribute specifies the offset to apply to the object. The "x-offset (integer(0:MAX))", "y-offset (integer(0:MAX))", and "z-offset (integer(0:MAX))" member attributes specify the offsets from the left, front, and Build Platform respectively in hundredths of millimeters (1/2540th of an inch).

8.1.8.3 object-size (collection)

This member attribute specifies the dimensions of the object. The "x-dimension (integer(1:MAX))", "y-dimension (integer(1:MAX))", and "z-dimension (integer(1:MAX))" member attributes specify the dimensions in hundredths of millimeters (1/2540th of an inch).

8.1.8.4 object-uuid (uri)

This member attribute specifies the object's unique identifier that **MUST** be a 45-octet "urn:uuid" URI [RFC4122].

8.1.9 print-supports (type2 keyword)

This **REQUIRED** 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.

8.2 Job Status Attributes

Table 14 lists the "-actual" Job Status attributes that provide the receipt of Job Template attributes that were used when processing a Job.

Table 14 - IPP 3D "-actual" Job Status Attributes

Job Status Attribute	Conformance
chamber-humidity-actual (1setOf integer(0:100))	RECOMMENDED
chamber-temperature-actual (1setOf integer(-273:MAX))	RECOMMENDED
materials-col-actual (1setOf collection)	REQUIRED
multiple-object-handling-actual (type2 keyword)	REQUIRED (note 1)
platform-temperature-actual (1setOf integer(-273:MAX))	REQUIRED (note 2)
print-accuracy-actual (collection)	REQUIRED
print-base-actual (1setOf type2 keyword)	REQUIRED
print-objects-actual (1setOf collection)	REQUIRED (note 1)
print-supports-actual (1setOf type2 keyword)	REQUIRED

Note 1: REQUIRED for Printers that support the 'application/pdf' document format.

Note 2: REQUIRED for Printers that provide a temperature-controlled Build Platform.

8.2.1 chamber-humidity-actual (1setOf integer(0:100))

This Job Status attribute contains the chamber relative humidity value(s) that were used throughout the processing of the Job. Printers that support humidity control SHOULD support this attribute.

8.2.2 chamber-temperature-actual (1setOf integer(-273:MAX))

This Job Status attribute contains the chamber temperature(s) in degrees Celsius that were used throughout the processing of the Job. Printers that support a temperature-controlled build chamber SHOULD support this attribute.

8.2.3 materials-col-actual (1setOf collection)

This REQUIRED Job Status attribute contains the material(s) that were used when processing the Job.

8.2.4 multiple-object-handling-actual (type2 keyword)

This CONDITIONALLY REQUIRED Job Status attribute specifies how multiple objects were handled in the Job. Printers that support the 'application/pdf' document format MUST support this attribute.

8.2.5 print-accuracy-actual (collection)

This REQUIRED Job Status attribute specifies the accuracy of the processed Job.

8.2.6 platform-temperature-actual (1setOf integer(-273:MAX))

This CONDITIONALLY REQUIRED Job Status attribute specifies the Build Platform temperature(s) that were used during the process of the Job. Printers that provide a temperature-controlled Build Platform MUST support this attribute.

8.2.7 print-accuracy-actual (1setOf collection)

This REQUIRED Job Status attribute lists the general positioning and feature accuracies that were used during the processing of the Job.

8.2.8 print-base-actual (1setOf type2 keyword)

This REQUIRED Job Status attribute specifies whether rafts, brims, or skirts were printed during the processing of the Job.

8.2.9 print-objects-actual (1setOf collection)

This CONDITIONALLY REQUIRED Job Status attribute lists the objects that were processed. Printers that support the 'application/pdf' document format MUST support this attribute.

8.2.10 print-supports-actual (1setOf type2 keyword)

This REQUIRED Job Status attribute specifies whether supports were printed during the processing of the Job.

8.3 Printer Description Attributes

8.3.1 accuracy-units-supported (1setOf type2 keyword)

This REQUIRED Printer Description attribute specifies the supported "accuracy-units" member attribute values.

8.3.2 chamber-humidity-default (integer(0:100) | no-value)

This Printer Description attribute specifies the default relative humidity of the build chamber as a percentage. Printers that support the "chamber-humidity" Job Template attribute (section 8.1.1) MUST support this attribute.

8.3.3 chamber-humidity-supported (boolean)

This Printer Description attribute specifies whether the "chamber-humidity" Job Template attribute (section 8.1.1) is supported. Printers that support the "chamber-humidity" Job Template attribute MUST support this attribute.

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

This Printer Description attribute contains the default temperature of the build chamber in degrees Celsius, if configured. Printers that support the "chamber-temperature" Job Template attribute (section 8.1.2) MUST support this attribute.

8.3.5 chamber-temperature-supported (1setOf (integer(-273:MAX) | rangeOfInteger(-273:MAX)))

This Printer Description attribute lists the supported temperatures (or ranges of temperatures) of the build chamber in degrees Celsius. Printers that support the "chamber-temperature" Job Template attribute (section 8.1.2) MUST support this attribute.

8.3.6 material-amount-units-supported (1setOf type2 keyword)

This Printer Description attribute lists the supported "material-amount-units" values for the Printer. This attribute MUST be supported if the "material-amount-units" member attribute (Section 8.1.3.2) is supported.

8.3.7 material-diameter-supported (1setOf (integer | rangeOfInteger))

This CONDITIONALLY REQUIRED Printer Description attribute lists the supported "material-diameter" values for the Printer. This attribute MUST be supported if the "material-diameter" member attribute (Section 8.1.3.4) is supported.

8.3.8 material-nozzle-diameter-supported (1setOf (integer | rangeOfInteger))

This Printer Description attribute lists the supported "material-nozzle-diameter" values for the Printer. This attribute MUST be supported if the "material-nozzle-diameter" member attribute (Section 8.1.3.9) is supported.

8.3.9 material-purpose-supported (1setOf type2 keyword)

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

8.3.10 material-rate-supported (1setOf (integer | rangeOfInteger)

This Printer Description attribute lists the supported "material-rate" values for the Printer. This attribute MUST be supported if the "material-rate" member attribute (Section 8.1.3.11) is supported.

8.3.11 material-rate-units-supported (1setOf type2 keyword)

This Printer Description attribute lists the supported "material-rate-units" values for the Printer. This attribute MUST be supported if the "material-rate-units" member attribute (Section 8.1.3.12) is supported.

8.3.12 material-shell-thickness-supported (1setOf (integer(1:MAX) | rangeOfInteger(1:MAX)))

This REQUIRED Printer Description attribute specifies the supported "material-shell-thickness" values (or ranges of values) in nanometers.

8.3.13 material-temperature-supported (1setOf (integer(-273:MAX) | rangeOfInteger(-273:MAX)))

This CONDITIONALLY REQUIRED Printer Description attribute specifies the supported "material-temperature" values (or ranges of values) in degrees Celsius. This attribute MUST be supported if the "material-temperature" member attribute (Section 8.1.3.15) is supported.

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

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

8.3.15 materials-col-database (1setOf collection)

This RECOMMENDED 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.

In order to optimize the total size of this attribute, Printers MAY omit member attributes that allow the full range of supported values in a particular collection. For example, a Printer that supports generic PLA filament can report a single collection value:

```
materials-col-database =  
  { material-name="Generic PLA Filament" material-key="generic-pla"  
    material-diameter=285 material-temperature=215-235 }
```

Such "wildcard" values can be combined with more precise collections that identify a specific product, for example:

```
materials-col-database =  
  { material-name="Generic PLA Filament" material-key="generic-pla"  
    material-diameter=285 material-temperature=215-235 },  
  { material-name="Example Corp Flexible Midnight Blue PLA" material-  
    key="com.example.flexible-midnight-blue" material-  
    color="com.example.midnight-blue_000027" material-diameter=285 material-  
    temperature=210-225 }
```

8.3.16 materials-col-default (1setOf collection)

This REQUIRED Printer Description attribute lists the default materials that will be used if the "materials-col" Job Template attribute (Section 8.1.1) is not specified.

8.3.17 materials-col-ready (1setOf collection)

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

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

This REQUIRED Printer Description attribute lists the "materials-col" member attributes that are supported by the Printer. Printers MUST include the following values: 'material-fill-density', 'material-key', 'material-name', 'material-purpose', 'material-shell-thickness', and 'material-type'.

8.3.19 max-materials-col-supported (integer(1:MAX))

This REQUIRED Printer Description attribute specifies the maximum number of values that can be provided with the "materials-col" Job Template attribute (section 8.1.1).

8.3.20 multiple-object-handling-default (type2 keyword)

This CONDITIONALLY REQUIRED Printer Description attribute specifies the default "multiple-object-handling" value. Printers that support the 'application/pdf' Document format MUST support this attribute.

8.3.21 multiple-object-handling-supported (1setOf type2 keyword)

This CONDITIONALLY REQUIRED Printer Description attribute lists the supported "multiple-object-handling" values. Printers that support the 'application/pdf' Document format MUST support this attribute.

8.3.22 pdf-features-supported (1setOf type2 keyword)

This CONDITIONALLY REQUIRED Printer Description attribute lists the PDF features that are supported by the Printer. Printers that support the 'application/pdf' Document format MUST support this attribute.

Values include:

'prc': The Printer supports 3D objects in the Product Representation Compact (PRC) format [ISO14739-1].

'u3d': The Printer supports 3D objects in the Universal 3D (U3D) format [ECMA363].

8.3.23 platform-shape (type2 keyword)

This RECOMMENDED Printer Description attribute describes the overall shape of the build platform. Values include:

'ellipse': The build platform is elliptical, forming a cylindrical build volume.

'rectangle': The build platform is rectangular, forming a cubic build volume.

8.3.24 platform-temperature-default (integer(-273:MAX))

This CONDITIONALLY REQUIRED Printer Description attribute specifies the default "platform-temperature" value. Printers that control the temperature of the Build Platform MUST support this attribute.

8.3.25 platform-temperature-supported (1setOf (integer(-273:MAX) | rangeOfInteger(-273:MAX)))

This CONDITIONALLY REQUIRED Printer Description attribute lists the supported "platform-temperature" values and/or ranges. Printers that control the temperature of the Build Platform MUST support this attribute.

8.3.26 print-accuracy-default (collection)

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

8.3.27 print-accuracy-supported (collection)

This REQUIRED Printer Description attribute specifies the best "print-accuracy" value that is supported by the Printer.

8.3.28 print-base-default (type2 keyword)

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

8.3.29 print-base-supported (1setOf type2 keyword)

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

8.3.30 print-objects-supported (1setOf type2 keyword)

This CONDITIONALLY REQUIRED Printer Description attribute specifies which "print-objects" member attributes are supported. Printers that support the 'application/pdf' Document format MUST support this attribute.

8.3.31 print-supports-default (type2 keyword)

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

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

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

8.3.33 printer-volume-supported (collection)

This REQUIRED Printer Description attribute specifies the maximum build volume supported by the Printer. Table 15 lists the REQUIRED member attributes.

Table 15 - REQUIRED "printer-volume-supported" Member Attributes

Member Attribute
x-dimension (integer(1:MAX))
y-dimension (integer(1:MAX))
z-dimension (integer(1:MAX))

8.3.33.1 x-dimension (integer(1:MAX))

This member attributes specifies the width of the build volume in hundredths of millimeters (1/2540th of an inch).

8.3.33.2 y-dimension (integer(1:MAX))

This member attributes specifies the depth of the build volume in hundredths of millimeters (1/2540th of an inch).

8.3.33.3 z-dimension (integer(1:MAX))

This member attributes specifies the height of the build volume in hundredths of millimeters (1/2540th of an inch).

8.4 Printer Status Attributes

8.4.1 chamber-humidity-current (integer(0:100) | unknown)

This Printer Status attribute reports the current relative humidity of the build chamber as a percentage. Printers that support the "chamber-humidity" Job Template attribute (section 8.1.1) MUST support this attribute.

8.4.2 chamber-temperature-current (integer(-273:MAX) | unknown)

This Printer Status attribute reports the current temperature of the build chamber in degrees Celsius, if known. Printers that support the "chamber-temperature" Job Template attribute (section 8.1.2) MUST support this attribute.

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

This Printer Status 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. The referenced images MUST be PNG [RFC2083] or JPEG [JFIF] format.

9. New Values for Existing Attributes

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

This specification registers the new REQUIRED value 'ipp-3d' for the "ipp-features-supported" Printer Description attribute.

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

This specification registers the following new values for the "printer-state-reasons" Printer Status attribute:

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

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

'chamber-failure': A chamber has failed and requires maintenance or replacement.

'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.

'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.

'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.

'platform-cooling': A Build Platform is being cooled.

'platform-failure': A Build Platform has failed and requires maintenance or replacement.

'platform-heating': A Build Platform is being heated.

'platform-temperature-high': The temperature of a Build Platform is too high.

'platform-temperature-low': The temperature of a Build Platform is too low.

10. Conformance Requirements

10.1 Printer Conformance Requirements

In order for a Printer to claim conformance to this specification, a Printer **MUST** support:

1. The required discovery protocols in section 5;
2. The required transports and resource paths in section 6.1;
3. The required HTTP features in section 6.2;
4. The required IPP operations in section 6.3;
5. The required IPP attributes in sections 6.4 through 6.9;
6. The required document formats in section 7;
7. The additional values defined in section 9;
8. The internationalization considerations in section 11; and
9. The security considerations in section 12.

10.2 Client Conformance Requirements

In order for a Client to claim conformance to this specification, a Client **MUST** support:

1. The required discovery protocols in section 5;
2. The required transports and resource paths in section 6.1;
3. The required HTTP features in section 6.2;
4. The required IPP operations in section 6.3;
5. The required IPP attributes in sections 6.4 through 6.9;
6. The required document formats in section 7;
7. The additional values defined in section 9;
8. The internationalization considerations in section 11; and
9. The security considerations in section 12.

11. Internationalization Considerations

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

1. The Universal Character Set (UCS) Transformation Format -- 8 bit (UTF-8) [STD63] encoding of Unicode [UNICODE] [ISO10646]; and
2. 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 specification 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 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

12. Security Considerations

In addition to the security considerations described in the IPP/1.1: Model and Semantics [STD92], 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

12.1 Confidentiality

Clients and Printers MUST provide confidentiality of data in transit using either an interface providing physical security such as USB or using TLS encryption [RFC5246] over unsecured/network connections,

12.2 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.

12.3 Physical Safety

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

12.4 Material Safety

Printers MUST restrict usage and combination of materials to those that can be safely printed. Access controls (section 12.2) MAY be used to allow authorized End 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.

12.5 Temperature Control

Printers MUST validate 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, hazardous emissions, explosions, and/or fires.

13. IANA and PWG Considerations

13.1 Attribute Registrations

The attributes defined in this specification will be published by IANA according to the procedures in IPP/1.1 Model and Semantics [STD92] section 7.2 in the following file:

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

The registry entries will contain the following information:

Document Status attributes: -----	Reference -----
chamber-humidity-actual (1setOf integer(0:100))	[PWG5100.21]
chamber-temperature-actual (1setOf integer(-273:MAX))	[PWG5100.21]
materials-col-actual (1setOf collection)	[PWG5100.21]
< member attributes are the same as materials-col >	[PWG5100.21]
multiple-object-handling-actual (type2 keyword)	[PWG5100.21]
platform-temperature-actual (1setOf integer(-273:MAX))	[PWG5100.21]
print-accuracy-actual (collection)	[PWG5100.21]
< member attributes are the same as print-accuracy >	[PWG5100.21]
print-base-actual (1setOf type2 keyword)	[PWG5100.21]
print-objects-actual (1setOf collection)	[PWG5100.21]
< member attributes are the same as print-objects >	[PWG5100.21]
print-supports-actual (1setOf type2 keyword)	[PWG5100.21]
Document Template attributes: -----	Reference -----
chamber-humidity (integer(0:100))	[PWG5100.21]
chamber-temperature (integer(-273:MAX))	[PWG5100.21]
materials-col (1setOf collection)	[PWG5100.21]
material-amount (integer(0:MAX))	[PWG5100.21]
material-amount-units (type2 keyword)	[PWG5100.21]
material-color (type2 keyword)	[PWG5100.21]
material-diameter (integer(0:MAX))	[PWG5100.21]
material-diameter-tolerance (integer(0:MAX))	[PWG5100.21]
material-fill-density (integer(0:100))	[PWG5100.21]
material-key (keyword)	[PWG5100.21]
material-name (name(MAX))	[PWG5100.21]
material-nozzle-diameter (integer(0:MAX))	[PWG5100.21]
material-purpose (1setOf type2 keyword)	[PWG5100.21]
material-rate (integer(1:MAX))	[PWG5100.21]
material-rate-units (type2 keyword)	[PWG5100.21]
material-retraction (boolean)	[PWG5100.21]
material-shell-thickness (integer(0:MAX))	[PWG5100.21]
material-temperature (integer(-273:MAX) rangeOfInteger(-273:MAX))	[PWG5100.21]

material-type (type2 keyword name(MAX))	[PWG5100.21]
multiple-object-handling (type2 keyword)	[PWG5100.21]
platform-temperature (integer(-273:MAX))	[PWG5100.21]
print-accuracy (collection)	[PWG5100.21]
accuracy-units (type2 keyword)	[PWG5100.21]
x-accuracy (integer(0:MAX))	[PWG5100.21]
y-accuracy (integer(0:MAX))	[PWG5100.21]
z-accuracy (integer(0:MAX))	[PWG5100.21]
print-base (type2 keyword)	[PWG5100.21]
print-objects (1setOf collection)	[PWG5100.21]
document-number (integer(1:MAX))	[PWG5100.21]
object-offset (collection)	[PWG5100.21]
x-offset (integer(0:MAX))	[PWG5100.21]
y-offset (integer(0:MAX))	[PWG5100.21]
z-offset (integer(0:MAX))	[PWG5100.21]
object-size (collection)	[PWG5100.21]
x-dimension (integer(1:MAX))	[PWG5100.21]
y-dimension (integer(1:MAX))	[PWG5100.21]
z-dimension (integer(1:MAX))	[PWG5100.21]
object-uuid (uri)	[PWG5100.21]
print-supports (type2 keyword)	[PWG5100.21]

Job Status attributes:

Reference

-----	-----
chamber-humidity-actual (1setOf integer(0:100))	[PWG5100.21]
chamber-temperature-actual (1setOf integer(-273:MAX))	[PWG5100.21]
materials-col-actual (1setOf collection)	[PWG5100.21]
< member attributes are the same as materials-col >	[PWG5100.21]
multiple-object-handling-actual (type2 keyword)	[PWG5100.21]
platform-temperature-actual (1setOf integer(-273:MAX))	[PWG5100.21]
print-accuracy-actual (collection)	[PWG5100.21]
< member attributes are the same as print-accuracy >	[PWG5100.21]
print-base-actual (1setOf type2 keyword)	[PWG5100.21]
print-objects-actual (1setOf collection)	[PWG5100.21]
< member attributes are the same as print-objects >	[PWG5100.21]
print-supports-actual (1setOf type2 keyword)	[PWG5100.21]

Job Template attributes:

Reference

-----	-----
chamber-humidity (integer(0:100))	[PWG5100.21]
chamber-temperature (integer(-273:MAX))	[PWG5100.21]
materials-col (1setOf collection)	[PWG5100.21]
material-amount (integer(0:MAX))	[PWG5100.21]
material-amount-units (type2 keyword)	[PWG5100.21]
material-color (type2 keyword)	[PWG5100.21]
material-diameter (integer(0:MAX))	[PWG5100.21]
material-diameter-tolerance (integer(0:MAX))	[PWG5100.21]
material-fill-density (integer(0:100))	[PWG5100.21]
material-key (keyword)	[PWG5100.21]

```

material-name (name(MAX)) [PWG5100.21]
material-nozzle-diameter (integer(0:MAX)) [PWG5100.21]
material-purpose (1setOf type2 keyword) [PWG5100.21]
material-rate (integer(1:MAX)) [PWG5100.21]
material-rate-units (type2 keyword) [PWG5100.21]
material-retraction (boolean) [PWG5100.21]
material-shell-thickness (integer(0:MAX)) [PWG5100.21]
material-temperature (integer(-273:MAX) | rangeOfInteger(-273:MAX))
[PWG5100.21]
material-type (type2 keyword | name(MAX)) [PWG5100.21]
multiple-object-handling (type2 keyword) [PWG5100.21]
platform-temperature (integer(-273:MAX)) [PWG5100.21]
print-accuracy (collection) [PWG5100.21]
accuracy-units (type2 keyword) [PWG5100.21]
x-accuracy (integer(0:MAX)) [PWG5100.21]
y-accuracy (integer(0:MAX)) [PWG5100.21]
z-accuracy (integer(0:MAX)) [PWG5100.21]
print-base (type2 keyword) [PWG5100.21]
print-objects (1setOf collection) [PWG5100.21]
document-number (integer(1:MAX)) [PWG5100.21]
object-offset (collection) [PWG5100.21]
x-offset (integer(0:MAX)) [PWG5100.21]
y-offset (integer(0:MAX)) [PWG5100.21]
z-offset (integer(0:MAX)) [PWG5100.21]
object-size (collection) [PWG5100.21]
x-dimension (integer(1:MAX)) [PWG5100.21]
y-dimension (integer(1:MAX)) [PWG5100.21]
z-dimension (integer(1:MAX)) [PWG5100.21]
object-uuid (uri) [PWG5100.21]
print-supports (type2 keyword) [PWG5100.21]

```

Printer Description attributes:	Reference
-----	-----
accuracy-units-supported (1setOf type2 keyword)	[PWG5100.21]
chamber-humidity-default (integer(0:100) no-value)	[PWG5100.21]
chamber-humidity-supported (boolean)	[PWG5100.21]
chamber-temperature-default (integer(-273:MAX) no-value)	[PWG5100.21]
chamber-temperature-supported (1setOf (integer(-273:MAX) rangeOfInteger(-273:MAX)))	[PWG5100.21]
material-amount-units-supported (1setOf type2 keyword)	[PWG5100.21]
material-diameter-supported (1setOf (integer(0:MAX) rangeOfInteger(0:MAX)))	[PWG5100.21]
material-nozzle-diameter-supported (1setOf (integer(0:MAX) rangeOfInteger(0:MAX)))	[PWG5100.21]
material-purpose-supported (1setOf type2 keyword)	[PWG5100.21]
material-rate-supported (1setOf (integer(1:MAX) rangeOfInteger(1:MAX)))	[PWG5100.21]
material-rate-units-supported (1setOf type2 keyword)	[PWG5100.21]

material-shell-thickness-supported (1setOf (integer(0:MAX) rangeOfInteger(0:MAX)))	[PWG5100.21]
material-temperature-supported (1setOf (integer(-273:MAX) rangeOfInteger(-273:MAX)))	[PWG5100.21]
material-type-supported (1setOf type2 keyword)	[PWG5100.21]
materials-col-database (1setOf collection)	[PWG5100.21]
< member attributes are the same as materials-col >	[PWG5100.21]
materials-col-default (1setOf collection)	[PWG5100.21]
< member attributes are the same as materials-col >	[PWG5100.21]
materials-col-ready (1setOf collection)	[PWG5100.21]
< member attributes are the same as materials-col >	[PWG5100.21]
materials-col-supported (1setOf type2 keyword)	[PWG5100.21]
max-materials-col-supported (integer(1:MAX))	[PWG5100.21]
multiple-object-handling-default (type2 keyword)	[PWG5100.21]
multiple-object-handling-supported (1setOf type2 keyword)	[PWG5100.21]
pdf-features-supported (1setOf type2 keyword)	[PWG5100.21]
platform-shape (type2 keyword)	[PWG5100.21]
platform-temperature-default (integer(-273:MAX))	[PWG5100.21]
platform-temperature-supported (1setOf (integer(-273:MAX) rangeOfInteger(-273:MAX)))	[PWG5100.21]
print-accuracy-supported (collection)	[PWG5100.21]
< member attributes are the same as print-accuracy >	[PWG5100.21]
print-base-default (type2 keyword)	[PWG5100.21]
print-base-supported (1setOf type2 keyword)	[PWG5100.21]
print-objects-supported (1setOf type2 keyword)	[PWG5100.21]
print-supports-default (type2 keyword)	[PWG5100.21]
print-supports-supported (1setOf type2 keyword)	[PWG5100.21]
printer-volume-supported (collection)	[PWG5100.21]
x-dimension (integer(1:MAX))	[PWG5100.21]
y-dimension (integer(1:MAX))	[PWG5100.21]
z-dimension (integer(1:MAX))	[PWG5100.21]
Printer Status attributes:	Reference
-----	-----
chamber-humidity-current (integer(0:100) unknown)	[PWG5100.21]
chamber-temperature-current (integer(-273:MAX) unknown)	[PWG5100.21]
printer-camera-image-uri (1setOf uri)	[PWG5100.21]

13.2 Keyword Value Registrations

The keywords defined in this specification will be published by IANA according to the procedures in IPP/1.1 Model and Semantics [STD92] section 7.1 in the following file:

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

The registry entries will contain the following information:

Attributes (attribute syntax)

Keyword Attribute Value	Reference
accuracy-units (type2 keyword)	[PWG5100.21]
mm	[PWG5100.21]
nm	[PWG5100.21]
um	[PWG5100.21]
accuracy-units-supported (1setOf type2 keyword)	[PWG5100.21]
< any accuracy-units values >	[PWG5100.21]
ipp-features-supported (1setOf type2 keyword)	[PWG5100.13]
ipp-3d	[PWG5100.21]
material-amount-units (type2 keyword)	[PWG5100.21]
g	[PWG5100.21]
kg	[PWG5100.21]
l	[PWG5100.21]
m	[PWG5100.21]
ml	[PWG5100.21]
mm	[PWG5100.21]
material-color (type2 keyword)	[PWG5100.21]
< any "media" color name >	[PWG5100.21]
material-purpose (1setOf type2 keyword)	[PWG5100.21]
all	[PWG5100.21]
base	[PWG5100.21]
in-fill	[PWG5100.21]
shell	[PWG5100.21]
support	[PWG5100.21]
material-rate-units (type2 keyword)	[PWG5100.21]
mg_second	[PWG5100.21]
ml_second	[PWG5100.21]
mm_second	[PWG5100.21]
material-type (type2 keyword)	[PWG5100.21]
abs	[PWG5100.21]
abs-carbon-fiber	[PWG5100.21]
abs-carbon-nanotube	[PWG5100.21]
chocolate	[PWG5100.21]
gold	[PWG5100.21]
nylon	[PWG5100.21]
pet	[PWG5100.21]
photopolymer	[PWG5100.21]
pla	[PWG5100.21]
pla-conductive	[PWG5100.21]
pla-dissolvable	[PWG5100.21]
pla-flexible	[PWG5100.21]
pla-magnetic	[PWG5100.21]
pla-steel	[PWG5100.21]
pla-stone	[PWG5100.21]
pla-wood	[PWG5100.21]
polycarbonate	[PWG5100.21]
silver	[PWG5100.21]
titanium	[PWG5100.21]

```

    wax [PWG5100.21]
materials-col-supported (1setOf type2 keyword) [PWG5100.21]
  < any materials-col member attribute name > [PWG5100.21]
multiple-object-handling (type2 keyword) [PWG5100.21]
  auto [PWG5100.21]
  best-fit [PWG5100.21]
  best-quality [PWG5100.21]
  best-speed [PWG5100.21]
  one-at-a-time [PWG5100.21]
multiple-object-handling-actual (1setOf type2 keyword) [PWG5100.21]
  < any multiple-object-handling Job Template attribute value > [PWG5100.21]
multiple-object-handling-default (type2 keyword) [PWG5100.21]
  < any multiple-object-handling Job Template attribute value > [PWG5100.21]
multiple-object-handling-supported (1setOf type2 keyword) [PWG5100.21]
  < any multiple-object-handling Job Template attribute value > [PWG5100.21]
pdf-features-supported (1setOf type2 keyword) [PWG5100.21]
  prc [PWG5100.21]
  u3d [PWG5100.21]
platform-shape (type2 keyword) [PWG5100.21]
  ellipse [PWG5100.21]
  rectangle [PWG5100.21]
print-base (type2 keyword) [PWG5100.21]
  brim [PWG5100.21]
  none [PWG5100.21]
  raft [PWG5100.21]
  skirt [PWG5100.21]
  standard [PWG5100.21]
print-base-actual (1setOf type2 keyword) [PWG5100.21]
  < any print-base Job Template attribute value > [PWG5100.21]
print-base-default (type2 keyword) [PWG5100.21]
  < any print-base Job Template attribute value > [PWG5100.21]
print-base-supported (1setOf type2 keyword) [PWG5100.21]
  < any print-base Job Template attribute value > [PWG5100.21]
print-objects-supported (1setOf type2 keyword) [PWG5100.21]
  < any print-objects member attribute name > [PWG5100.21]
print-supports (type2 keyword) [PWG5100.21]
  material [PWG5100.21]
  none [PWG5100.21]
  standard [PWG5100.21]
print-supports-actual (1setOf type2 keyword) [PWG5100.21]
  < any print-supports Job Template attribute value > [PWG5100.21]
print-supports-default (type2 keyword) [PWG5100.21]
  < any print-supports Job Template attribute value > [PWG5100.21]
print-supports-supported (1setOf type2 keyword) [PWG5100.21]
  < any print-supports Job Template attribute value > [PWG5100.21]
printer-state-reasons (1setOf type2 keyword) [RFC8011]

```

camera-failure	[PWG5100.21]
chamber-cooling	[PWG5100.21]
chamber-failure	[PWG5100.21]
chamber-heating	[PWG5100.21]
chamber-temperature-high	[PWG5100.21]
chamber-temperature-low	[PWG5100.21]
extruder-cooling	[PWG5100.21]
extruder-failure	[PWG5100.21]
extruder-heating	[PWG5100.21]
extruder-jam	[PWG5100.21]
extruder-temperature-high	[PWG5100.21]
extruder-temperature-low	[PWG5100.21]
fan-failure	[PWG5100.21]
lamp-at-eol	[PWG5100.21]
lamp-failure	[PWG5100.21]
lamp-near-eol	[PWG5100.21]
laser-at-eol	[PWG5100.21]
laser-failure	[PWG5100.21]
laser-near-eol	[PWG5100.21]
material-empty	[PWG5100.21]
material-low	[PWG5100.21]
material-needed	[PWG5100.21]
motor-failure	[PWG5100.21]
platform-cooling	[PWG5100.21]
platform-failure	[PWG5100.21]
platform-heating	[PWG5100.21]
platform-temperature-high	[PWG5100.21]
platform-temperature-low	[PWG5100.21]

13.3 Service Type Registration

The DNS-SD service type defined in this specification will be published by IANA according to the procedures in Internet Assigned Numbers Authority (IANA) Procedures for the Management of the Service Name and Transport Protocol Port Number Registry [BCP165].

The registration template is as follows:

Service Name: ipp3d

Transport Protocol(s): tcp

Assignee/Contact: Michael Sweet, msweet@apple.com

Description: 3D Print services (3D printers) using the Internet Printing Protocol over HTTPS.

Reference: <https://ftp.pwg.org/pub/pwg/candidates/cs-ipp3d11-20190329-5100.21.pdf>

Port Number:

Service Code:

Known Unauthorized Uses:

Assignment Notes: Change controller is The Printer Working Group, c/o The IEEE Industry Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ 08854, USA

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16. Object Definition Languages (ODLs)

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

16.1 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 registered MIME media type for the original Microsoft published specification is "application/vnd.ms-3mfdocument". The MIME media type for the 3MF Consortium's published specification is "model/3mf".

16.2 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'.

16.3 Portable Document Format (PDF)

PDF [ISO32000] is widely supported for 2D printing and has two 3D formats that are used to embed 3D objects - PRC [ISO14739-1] and U3D [ECMA363]. The registered MIME media type for PDF is "application/pdf".

16.4 Standard Tessellation Language (STL)

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

17. Design Choices

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

17.1 Units for Length Values

The default unit for most length values is hundredths of millimeters (1/2540th of an inch), matching the units for 2D printing and providing a range of 0.01mm to 21.47km. This was determined to be sufficient for the class of printers this specification targets.

17.2 Units for Thickness Values

The default unit for most thickness values is nanometers, which provides a range of 0.000001mm to 2.147m. This was determined to be sufficient for the class of printers this specification targets.

17.3 Use of Celsius for Temperatures

The various integer attributes for temperature use degrees Celsius. This was done because most existing printers and materials are specified using degrees Celsius. There is no advantage to using degrees Fahrenheit or Kelvin, and forcing Clients and Printers to perform additional unit conversions could cause safety issues. All temperature attributes use a range of -273 (absolute zero) to MAX (2147483647 - significantly hotter than our sun) to allow flexibility.

17.4 Explicit Units for Other Values

Some attributes have a companion "xxx-units" attribute that specifies an explicit unit for the given measurement(s). The initial list of unit values for each attribute has been limited to those necessary for current printers and technologies at the time of writing of this specification in order to minimize interoperability issues.

17.5 Intent vs. Process

The IPP Model [RFC8011], and more generally the PWG Semantic Model [PWG5108.1], have long focused on Job Tickets specifying "what" is wanted for the printed output vs. "how" that output is produced. This focus has served IPP well and allowed it to be used with wildly different printing technologies.

During the development of this specification, attributes that define a specific process or technological parameter have been introduced and later replaced by intent-based alternatives that allow an implementation to select suitable process-based parameters at print time, preserving the intrinsic value of such parameters without burdening the Client or End User with such things.

At the same time, some process parameters are needed for things like material specification. For example, a particular brand of PLA may require a higher melting temperature - this information might only be known to the End User, so the "materials-col" collection contains an member attribute to convey this process-specific parameter. The Printer advertises whether temperature is a valid material property in the "materials-col-supported" Printer Description attribute.

Finally, IPP does not prohibit the definition or use of process-based Job Template attributes for specific implementations. Such extension attributes can be listed in the "job-creation-attributes-supported" Printer Description attribute to notify Clients of their existence.

17.6 Choosing a Required Document Format

One of the design considerations of this specification is to choose an open, freely available file format for use as required document format. Having a required document format makes interoperability significantly easier, and using an open and freely available format allows developers of "consumer" printers to support IPP 3D. Several formats were considered, including STL, AMF, PDF, and 3MF.

While STL is a widely-implemented, open, and freely available file format, it lacks support for multiple materials and colors/textures, and has technical issues that cause "holes" in generated models.

While AMF supports multiple materials and does not have the "holes" issue, it is not freely available nor widely-implemented.

PDF is the most capable 3D format but is not freely available and has the interoperability problem of two separate and incompatible 3D object encodings: U3D and PRC. The "pdf-features-supported" Printer Description attribute (section 8.3.22) allows Clients to determine whether a 3D PDF file can be printed by the Printer.

3MF is open and freely available, supports multiple materials and color/textures, does not have the "holes" issue of STL, and has a freely available open source implementation that supports both creation and consumption of 3MF files.

18. Overview of Changes

18.1 IPP 3D Printing Extensions v1.1

The following changes were made since v1.0 of this document:

1. Made 3MF CONDITIONALLY REQUIRED for Printers that do Slicing, RECOMMEND support for a standard layered format otherwise.
2. Added the CONDITIONALLY REQUIRED "material-nozzle-diameter" and "material-retraction" member attributes for the "materials-col" Job Template attribute.
3. Added the RECOMMENDED "platform-shape" Printer Description attribute
4. Added the CONDITIONALLY REQUIRED "chamber-humidity" and "chamber-temperature" Job Template attributes.
5. Defined a naming convention for standard "material-type" values.