Resource Description for Additive Manufacturing – Supporting Scheduling and Provisioning

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***Abstract*—For an enhanced automated usage of 3D-printers in case of multiple available 3D-printers, such as in Cloud Manufacturing or Cloud Printing services, the requirement arises to select and provision suitable resources for user provided model files. As Additive Manufacturing (AM) consists of a number of different technologies, ranging from fabrication using thermoplastic extrusion to electron beam based curing of metal powder, the necessity is evident to enable users to describe limitations, capabilities, interfaces and requirements for a these resources in a machine readable and processable format. This resource description enables the discovery and provisioning of appropriate resources within a service composition, where 3D-printing resources are regarded as manufacturing services themselves. In order to compose a service from these hardware resources, the comprehensive description of such resources must be provided. With this work, we provide an abstract and universal capability description framework of such 3D-printing resources. The framework consists of an ontology for the resources of the AM Domain, a flexible XML schema and the implementation in a cloud-based 3D-printing system. With this resource description both hard- and software resources are universally defined. Applied to systems with multiple 3D-printers, a scheduling component is capable of resource discovery. This selection is based on the matching of described capabilities, status information and derived requirements from specific 3D-printing job definitions.**

***Keywords*—3D Printing; Additive Manufacturing; Resource Description; Capability Description; Service Selection; Service Discovery**

I. INTRODUCTION

For the efficient usage of 3D-printing resources in Cloud Manufacturing (CM) scenarios, it is necessary to schedule the existing resources. This scheduling is in accordance with the requirements of the users. 3D-printing resources are mainly 3D-printers of various types, makes and models. These 3D-printers are characterised by differing capabilities and constraints for their usage. In a cloud printing environment where these resources are considered part of a service, it is possible to compose them into new services to achieve tasks such the efficient execution of 3D-printing requests. This work offers a practical service composition framework and tool for the description required to establish service compositions within a 3D-printing service in the domain of Additive Manufacturing (AM). For this work, the applicability of the proposed resource description is analysed.

As 3D-printing encapsulates a number of different technologies, ranging from thermoplastic extrusion fabrication, over photopolymerisation to other methods, it is a prerequisite to understand these technologies. One thermoplastic extrusion based method is called Fused Deposition Modeling (FDM) (also Fused Filament Fabrication or Free Form Fabrication (FFF)). Fabrication on the basis of curing of photopolymers in a vat is called Stereolithography (SLA). Laser-based fabrication methods are either Selective Laser Melting (SLM) or Direct Metal Laser Sintering (DMLS). Other methods exist to create physical objects directly from digital models, such as Laminated Object Manufacturing (LOM). Besides the understanding of these technologies and methods, it is important to be able to describe them in a comprehensive and machine-understandable way. Furthermore, it is important to express the inherent and derived capabilities and restrictions of these technologies and machines. The different technologies do not only differ in the materials they are able to process but also in the quality that is achievable. They further differ in the geometric and structural features they can reproduce, in the cost they effect, and the means they are controlled by or programmed with. For the automated usage in a distributed service scenario, with a number of different 3D-printing resources involved, the service must be able to select an appropriate device or devices for any given user submitted task.

For the hardware providers, it is beneficial if their equipment is utilized to a high degree. This is required in order to amortise their assets on time and also to be ecologically sound [1]. For the users, such an automated and swift resource allocation is pertinent. This equates to a reduced turnaround time and also the promise of higher product quality due to optimum capability and requirements matching. For service operators, the automated resource allocation is an intrinsically motivated requirement for the operation of such a service.

With this work, a solution for the description of differing capabilities, restraints and requirements of various 3D-printing resources is provided. This solution provides an extensible, flexible, comprehensive and usable description format for the use in AM scenarios. The solution combines existing approaches for the description of resource capabilities and extends these for the usage in 3D-printing.

This work is motivated by the following four use cases:

3D-printer selection: The resource description, applied to a database of commercially available 3D-printers can serve as a purchasing guide for end-users/consumers or other potential buyers of 3D-printers [2], [3]. This will especially be the case if the information is readily available as a Web-service and supports pro-active user-questioning, e.g., a wizard.

Automated facility planning: In future modular factory designs, the dynamic reconfiguration of the shop floor [4] is becoming relevant. With a machine readable resource description, layouting and planning software can place the manufacturing resources at an appropriate location.

Scheduling in 3D-printing services: In this use case the resource description is the foundation for the scheduling algorithm that selects the most appropriate available 3D-printing resource for any given processing request, based on the constraints and preferences provided by the user and derived from the model data [5], [6].

Recommender systems for CAD development: Based on the resource description a software system can support Computer Aided Design (CAD) designers with information and recommendations for geometrical and topological features within models that are manufacturable with 3D-printing resources available to a company.

This work is structured as follows: Starting with related work in Sect. II, a review of existing publications is performed. In Sect. III, the approach for the resource description is described, its underlying concepts and sources as well as the implementation and evaluation. In the Sect. IV, the implementation and its results are discussed and analysed. Lastly, the Sect. V provides a summary of this work.

II. RELATED WORK

In the work by Pryor [7], the implementation of a 3D-printing service within an academic library is described. The system consists of two low-cost hobbyist 3D-printers and a 3D scanner. Of relevance to this work is the description of the workflow for the user handling. Pryor describes the processing workflow as purely manual with the data being deployed by the users either via a web form or email. The library staff performs sanity checking, pre-processing (i.e., positioning, slicing, machine code generation) and manual scheduling of the 3D-printer resource. The text does not provide an analysis of the time required for the staff to perform these tasks.

In the article by Vichare et al. [8], the authors propose a Unified Manufacturing Resource Model (UMRM) for the resource description of machines within the manufacturing domain. Specifically, the authors aim to describe Computer Numeric Control (CNC) machines and their associated tools in a unified way to represent the capabilities of these systems in their entirety. Their work provides a method to describe a CNC machine in an abstract sense for use in software, e.g., for simulations. As part of the collaborative peer-robot control system described in the work by Yao et al. [9], an ontology for a resource description is partially described on which we build our work. This ontology distinguishes between hardware and software resources, as well as capability and status description. The authors provide an exemplary Extensible Markup Language (XML) schema definition for such a resource description on which we extend upon. The *3D Printer Description File Format Specification* (3PP) by Adobe [10] is very relevant to this work, as it describes the 3D-printer's capabilities in XML format as deemed necessary by Adobe, presumably for the application within their software. This work contains an extensive listing of possible attributes relevant to a resource description on which we base our work. The 3PP format is limited to FDM 3D-printers. The definition includes hardware and material description but only partially caters for software support. In the publication by Chen et al. [11], the authors provide another approach to the problem of model-fabrication resource mismatch by the introduction on an abstract intermediary specification format. The authors propose this reducer-tuner model to abstract design implementations for the application to a variety of 3D-printers whereas our work proposes a 3D-printer resource description that enables the matching of suitable machines to specific model files. In the work by Dong et al. [12], the problem of scheduling in AM is handled by a rule-based management of autonomous nodes, i.e., 3D-printers. This system is based on an ontology for 3D-printing of which some excerpts are presented in this work. From this example, our work is influenced and extends on missing attributes. Yadekar et al. [13] propose a taxonomy for CM systems that are closely related to AM. This taxonomy is focused on the concept of uncertainty and only briefly discusses the taxonomical components that define the manufacturing resources. The main distinction for the authors is the division into soft and hard resource groups. In the work by Mortara et al. [14], a classification scheme for direct writing technologies, i.e., AM, is proposed. The authors define the scheme for three dimensions, namely technology, application, and materials. The properties of specific materials are discussed exemplary in brief. A listing of potential properties for the varying technologies and materials is missing.

III. MATERIALS AND METHODS

From existing literature and expertise, we construct an ontology that is described in the following section. This ontology is the basis for the extension of the properties proposed that are relevant to the domain of AM. In this work, we exclude concepts like business process related capabilities, and knowledge and abstract ability related mapping, i.e., it is not possible to express certain abilities of people, teams or companies, e.g., the level of knowledge for the design of objects for AM. The properties are derived from literature and 3D-printer documentations. The following requirements are expressed to guide the generation of the ontology and properties list:

RQ1 The ontology and properties list must be flexible and extensible. Flexibility means that for specific application scenarios where only subsets of properties and relations are of interest, these must be expressible within the proposed ontology or resource description. Extensibility denotes the property to be able to incorporate future, currently unforeseen, properties of technology and materials.

RQ2 The resource description must be able to reflect temporal, local and other ranges of validity and restrictions. Conditional validity is to be reflected. With this requirement we reflect the necessity that certain properties, e.g., material strength, are only valid and guaranteed for a certain period.

RQ3 The resource description must be able to distinguish between general concepts of things, e.g., 3D-printers and materials, that form a class and its individual instantiation that might have differing properties and attributes.

In this work, the following separation of information description is performed for the resource description:

Materials: Encompasses all physical materials that are processed, or used during the digital fabrication. Also includes physical materials that are required for the digital fabrication process as indirect or auxiliary material.

Software: Encompasses all software and Information technology (IT) components that are involved in the model creation phase, the object fabrication phase or that are used for the control and management of digital fabrication equipment.

Processes: Encompasses all intangible processes, data and information that is generated, consumed, transformed or influenced by in any phase of the digital fabrication process. Business processes are part of this grouping.

Technology: Encompasses all hardware and machine equipment that is used for the object fabrication, as well as pre- and post-processing.

We exclude status information and status dependent properties from our resource description and ontology.

The resource description must be able to reflect required properties and information of all currently available 3D-printing technologies, regardless of the technology classification following any schema, such as the classification by Gibson et al. [15], the classification by Williams et al. [16] or the ISO/ASTM Standard 52900:2015 [17] classification. This work identifies common attributes between technologies and enables technology specific properties. As a guideline for the creation of the ontology and the resource description itself a distinction between object classes and their actual instances is followed. Given the example of a 3D-printer, the class is formed of all 3D-printers from a certain manufacturer and are of a certain make share a number of attributes like physical volume and number of printheads. Those general attributes might be extended by attributes pertaining to a certain 3D-printer that belongs to a user and is situated at a physical location. The general attributes might also be altered for a specific 3D-printer, as it might weight more than the original 3D-printer due to added extensions or modifications, or its build envelope is smaller than the original's due to a hardware defect.

A. Sources

Properties are extracted from datasheets from the following manufacturers and models:

3D Systems, Inc.: ProJet 7000 SD & HD, ProX 950, sPro 140, ProX DMP 200, ProX 800, ProX SLS 500, ProJet CJP 360, ProJet 1200, CubePro
Arcam AB: Arcam Q10 Plus, Arcam Q20 Plus, Arcam A2X
B9Creations LLC: B9Creator V1.2
CEL: CELRobox
Deltaprintr: Delta Go
EnvisionTEC GmbH: 3D-Bioplotter Starter Series, SLCOM1
EOS GmbH: EOS M 100, EOS M 290, FORMIGA P 110, EOS P 396, EOSINT P 800
ExOne GmbH: S-Max, S-Print, M-Flex Prototype 3D Printer
FlashForge Corp.: Creator Pro 3D
Formlabs Inc.: Form 2
LulzBot/Aleph Objects, Inc.: TAZ 6
Makerbot Industries, LLC: Replicator+, Replicator Z18
Mcor Technologies Ltd.: ARKe, IRIS HD
Optomec Inc.: LENS 450, Aerosol Jet 200
Renishaw plc.: RenAM 500M
RepRap: Prusa i3
SeeMeCNC: ROSTOCK MAX V3
SLM Solutions Group AG: SLM 125, SLM 280 2.0
Stratasys Ltd.: uPrint SE, Objet24, Dimension Elite, Fortus 380mc, Objet1000 Plus
Ultimaker B.V.: Ultimaker 3, Ultimaker 2+
UP3D/Beijing Tiertime Technology Co., Ltd.: UPBOX+
voxeljet AG: VX 200, VX 2000
WASP c/o CSP s.r.l.: DeltaWASP 20 40 Turbo

Furthermore, properties and capability attributes are extracted from publicly available slicing software (e.g., *Slic3r* [18], *Cura* [19], and *Netfabb* [20]) and acquired through experimentation. On the ontological concept itself, we refer to the work by Gruber [21] and the book by Fensel [22]. Following the distinction of ontologies by Ameri and Dutta [23], we classify our ontology as lightweight. For the construction of the ontology a list of key terms is compiled from existing glossaries and literature.

B. Properties

The following properties are identified from literature and technology documentation. These properties are listed in the appendix in order to avoid a disruption of the text flow. The provided listing is sufficient to describe relevant properties of AM machinery, i.e., 3D-printers, and the associated materials.

The properties can be further classified as either static, e.g., the serial number of a 3D-printer or its coordinate system, or dynamic, e.g., the owner or location of a 3D-printer. Dynamic properties are often dependent properties, which is a further classification applied to the properties. Dependent properties are influenced and depend upon a 3D-printer component, e.g., the nozzle and its diameter, the material, e.g., surface roughness achievable differs for materials processable or parameters selected during the 3D-printing process. This classification is not provided with this work due to brevity. The properties in the listing are for the hardware resources, i.e., the 3D-printer as well as its components and the material associated with the 3D-printer.

C. Implementation

In this section the implementation of both the ontology and the relevant core classes are described. Furthermore, information on a possible scheduling metric based on a cost estimation method and the resulting information flow in the implemented service is described.

The ontology is constructed using the protégé software version 5.1.0, see http://protege.stanford.edu/. The ontology is generated based on the properties brought forward in Sect. III-B. The guiding principle for the ontology is the flexibility of the properties that are applicable to 3D-printers, material and inherent constraints. The ontology is created based on the identified properties and derived concepts from literature and documentation.

The implementation in software to manage the specific properties of the resource description and to evaluate the applicability of the description is performed in the proposed 3D-printing cloud service by the authors [24], [25].

The implementation in the service is performed to enable provisional scheduling for 3D-printing resources based on availability, build volume and processable material type. In scheduling, some form of ordering metric must be provided. In this work, this metric is based on a proposed cost metric as described further in the text.

The cost metric is defined in [26] and serves as a prototypical implementation of cost estimation within AM.

The cost is calculated as (see Eq. 1) follows:

$$\begin{aligned}\text{Cost} = {} & (\text{Discount}(T, P, U) + \text{Profit}(U)) \\ & \times (\text{Machine} + \text{Material}(O, P, S, SO) \times \text{Factor B} \\ & + \text{Duration}(O, S, SO) \times \text{Factor U} + \text{Factor A} \\ & + \text{Factor C}(O, P)) \end{aligned} \tag{1}$$

With the following abbreviations used in the equation: 1) T for team 2) P for 3D-printer 3) U for user 4) O for object 5) S for slicer and, 6) SO for slicing options The cost for a 3D-print is dependent upon the 3D-printer selected (base cost), the material that is consumed and the time required for 3D-printing. Within the service, these attributes are user selectable for each materialtype and 3D-printer that is under the control of the user.

Based on the cost metric, scheduling is implemented in the service as described below.

In Figure 1, the processing flow for the registration of a hardware resource with the 3D-printing service is depicted. In this figure, the user dispatches a 3D-printing requirement (Job) with the service for which a number of implicit and explicit requirements and restrictions are also deposited. A hardware resource registers its capabilities with the service, that is then stored with the resource registry. The service queries the resource registry for a suitable hardware resource for a job and issues the appropriate commands for a 3D-printing execution on this resource. On completion or failure, the user issuing the job is notified.

1) Core Classes: The core classes in the ontology are described in this section. A visual representation of the ontology is depicted in Figure 2. This graph is created using the *WebVOWL* service [27].

MaterialGroup and **Material**, these classes denote the materials that are relevant for the description of the capabilities of the 3D-printing resource. The materials have an influence on a number of quality properties, e.g., the surface roughness. The materials a 3D-printing resource can process are relevant for the selection of the appropriate 3D-printing resource.

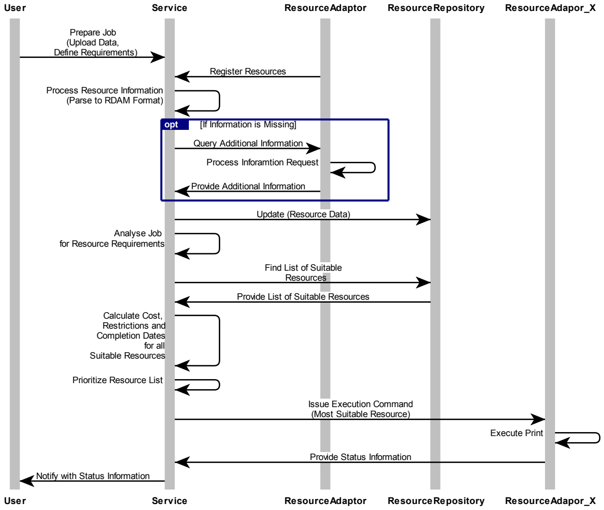

Fig. 1: Processing Flow for the Registration and Selection of a Hardware Resource

PrintingTechnology, **PrinterType**, and **Printer**, are classes to represent the underlying technology of a 3D-printing resource, e.g., a FDM based technology or a Electron Beam Melting (EBM) technology as well as the 3D-printer class which can be understood for example as a specific model line from a hardware manufacturer (e.g., the Replicator Series from Makerbot Industries). Hardware resources of a PrinterType have a number of common attributes that extend the PrintingTechnology. The Printer denotes the make of a specific PrinterType, e.g., the *MakerBot Replicator 2X* from Makerbot Industries. Instances of this Printer class have further common attributes extending the attributes of the PrinterType. Instances of the Printer class are actual 3D-printers that have further attributes like owner and a physical location.

PrinterComponent, is the class for the physical and immaterial components that are part of the specific 3D-printer. Every component can have a unbounded number of properties as described below. For example the printhead and its nozzles are components of a 3D-printer in the case of FDM technology and an electron source is a component of a EBM type 3D-printer.

Software, denotes all software that is used in the 3D-Printing Process (3D-PP). Software is used to control the 3D-printing resource, to convert files from one format into another, to prepare and process the files required for the control of the 3D-printer and to evaluate and monitor the 3D-print itself.

MProperty, this class is the generalisation of properties that

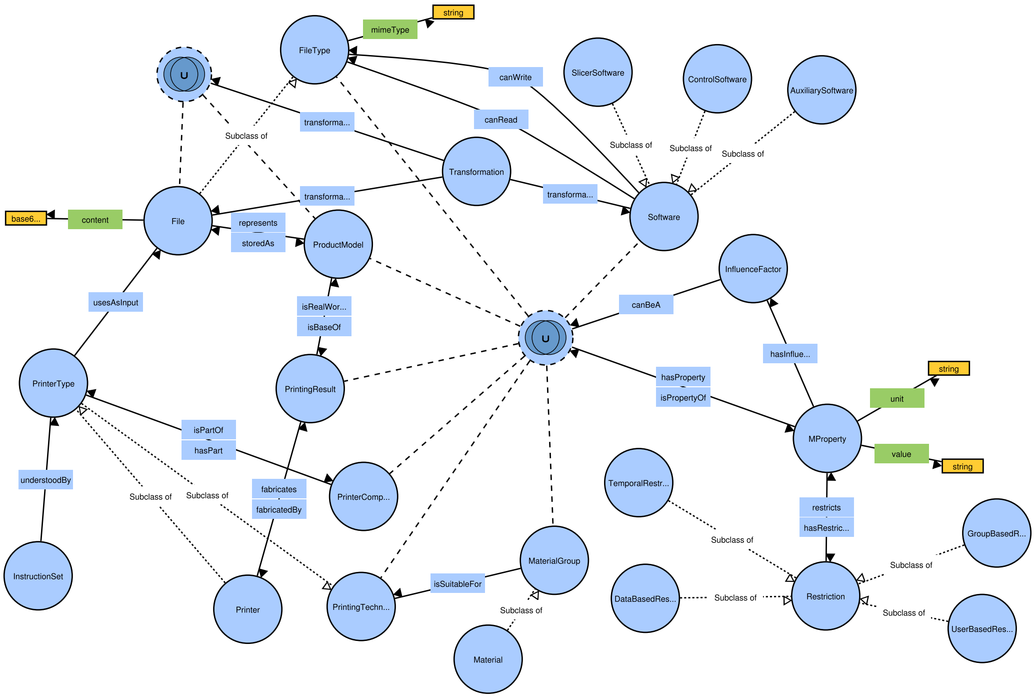

Fig. 2: 3D-printing Ontology

are applicable to either the Material, Materialgroup, PrintingTechnology, PrinterType, Printer, PrinterComponent, Software, ProductModel or File. The guiding principle for the creation of this ontology is to enable flexibility and expandability, so this generalised property can hold all properties listed above (see Sect. III-B) and future properties.

Restriction, is a class that reflects the ability to enable restrictions on MProperties as the properties can be applicable only for a specified period of time or for a certain group of people. For example the property of filament quality might be linked to a certain expiration date.

InfluenceFactor, is a class that reflects the multi-dimensional influences on properties by a defined number of factors. For example the nozzle diameter can influence the extrusion rate in case of a FDM 3D-printer.

D. Resource Description Schema

From the ontological concept, an XML schema definition is constructed which follows the principle of flexibility by encapsulation of properties in a flexible element. The property element is applicable to all relevant types of the schema, namely the PrintingTechnology, PrinterType, Printer, Printercomponent, Materialtype, and Material.

All properties are extended to allow for restrictions based on user, group or temporal conditions. The properties can be influenced by any other class of the schema to reflect interdependent relations between components. The following example justifies this construction: In the 3D-printer, the property of the material deposition rate is dependent upon the technology in use, the material processed and, in case of the FDM technology, the nozzle diameter of the extruder installed in the 3D-printer. See the following excerpt from the schema definition on the components properties and the implementation on the influencing factors:

```
<xs:complexType name="influence">
<xs:sequence minOccurs="1" maxOccurs="1">
<xs:element name="id" type="xs:ID"
  minOccurs="1" maxOccurs="1" />

<xs:choice>
<xs:element ref="tdp:MaterialType" />
<xs:element ref="tdp:Material" />
<xs:element ref="tdp:PrinterType" />
<xs:element ref="tdp:Printer" />
<xs:element ref="tdp:PrinterComponent" />
<xs:element ref="tdp:PrintingTechnology" />
</xs:choice>

<xs:element name="influenceMethod"
  type="xs:string" />
</xs:sequence>
</xs:complexType>

<xs:complexType name="validity">
<xs:sequence>
<xs:element name="id" type="xs:ID"
  minOccurs="1" maxOccurs="1" />
<xs:element name="validityCondition"
  type="xs:string"
  minOccurs="1" maxOccurs="unbounded" />
</xs:sequence>
</xs:complexType>
```

```
<xs:complexType name="mproperty">
<xs:sequence>
<xs:element name="unit"
  type="xs:normalizedString"
  minOccurs="1" maxOccurs="1"/>
<xs:element name="description"
  type="xs:normalizedString"
  minOccurs="1" maxOccurs="1"/>
<xs:element name="value"
  type="xs:normalizedString"
  minOccurs="1" maxOccurs="1"/>
<xs:element name="name"
  type="xs:normalizedString"
  minOccurs="1" maxOccurs="1" />
<xs:element name="added"
  type="xs:dateTime"
  minOccurs="1" maxOccurs="1" />
<xs:element ref="tdp:influence"
  maxOccurs="unbounded" />
<xs:element ref="tdp:validity"
  maxOccurs="unbounded" />
</xs:sequence>
</xs:complexType>
```

IV. DISCUSSION

The proposed resource description offers the ability to the user to select the appropriate 3D-printing resource in a scenario where restrictions for the suitable 3D-printing resources can be derived, from either the users input or from the provided data files. Within a 3D-printing service, the user is enabled to state preferences and restrictions, such as the desired quality of the 3D-printed object or cost restrictions, based on which the service itself can query appropriate hardware resources for their availability and suggest them to the user. Furthermore, based on the provided models the service can exclude certain hardware resources if they are not fitting for the task to be executed. For example, if the model file is analysed and found to contain features under a certain threshold, the hardware that is not capable of manufacturing features of this dimension are to be excluded.

A perceived problem with the flexibility of the ontology and resource description is the requirement for contextual property checking within the service itself. As opposed to strict formalities possible with the XML Schema Definition (XSD) definition, this flexibility hinders such formality checking. The 3D-printing service must be equipped with a component that is capable of evaluating the provided properties and check them for completeness, applicability and correctness. The resource description also allows for the encapsulation of third-party 3D-printing services within the 3D-printing service itself, where the capabilities of these services are regarded as a resource and described as such.

V. CONCLUSION

This work provides an ontology of the AM domain with extensible and flexible constructs. The derived XSD provides flexibility for extensions, based on future developments of 3D-printing hardware. The flexibility also allows for user-centric extensions and use-cases. The use case for this work is the deployment in a 3D-printing service but other use cases are also provided, such as the use within a recommender system for the design and modelling phase, or purchase recommendation systems.

In future work, it is recommended to extend the ontology to include concepts that enable the expression of immaterial capabilities and abilities, such as the expertise in certain domains, e.g., Aerospace engineering, medical engineering or bioprinting, in AM. Furthermore, it is recommended to enable the expression of proficiency in areas related to the 3D-printing lifecycle or process itself, e.g., proficiency with the design process, with the software / IT components or with legal and business concepts for AM.

ACKNOWLEDGMENT

The authors would like to thank Julia Holzschuh for her contributions to this work.

APPENDIX
LISTING OF RELEVANT PROPERTIES / ATTRIBUTES

1) Operating Temperature Min/Max 2) Operating Humidity Min/Max 3) Machine Weight/Length/Height/Depth 4) Install Size Weight/Length/Height/Depth 5) Build Envelope Height/Width/Depth/Radius 6) Machine Data Connection 7) Electrical Input Rating 8) Minimum Possible Hole Diameter 9) Positioning Accuracy X/Y/Z 10) Repeatability X/Y/Z 11) Print Accuracy X/Y/Z 12) Number of Extruders 13) Nozzle Diameter 14) Temperature Extruder Min/-Max 15) Layer Thickness Min/Max 16) Movement Speed Min/Max 17) Extrusion (Movement) Speed Min 18) Print Head Acceleration Max 19) Print Bed Speed X/Y/Z Min/-Max 20) Print Bed Acceleration X/Y/Z Min/Max 21) Print Bed Temperature Min/Max 22) Binder Material 23) Processable Material 24) Processable Material Grain Size Min/Max 25) Max Object Weight 26) Lead Time Influencing Factors 27) Lead Time Formula 28) Requires Personal Attendance During Print 29) Requires Manual Interaction for Start/End 30) Resolution X/Y/Z Min 31) Operation Allowed for User/-Group 32) Maximum Achievable Surface Roughness 33) Systematic Shrinkage during Build 34) Atmosphere Pressure/-Connection/Content 35) Consumables 36) Compressed Air Supply 37) Atmosphere Consumed 38) Beam Focus Diameter 39) Laser Energy 40) Scanning Speed Min/Max 41) Laser Type 42) Power Supply 43) Power Consumption 44) Power Phase Requirement 45) Precision Optics 46) Legal Conformity Certificates 47) Workstation Requirement Ram Min 48) Workstation Requirement OS 49) Workstation Requirement CPU Min 50) Workstation Requirement Net 51) Resolution X/Y/Z 52) Number of Jets 53) Accepted File Formats 54) Number of Colors 55) Color Model 56) Manufacturer 57) Model 58) Serial Numbers 59) Object Bounding Box X/Y/Z Min/Max 60) Min Supported Wall Thickness 61) Min Unsupported Wall Thickness 62) Min Supported Wire 63) Min Unsupported Wire 64) Min Emboss Detail Width/Height 65) Min Engraved Detail

Width/Height 66) Min Escape Holes 67) Clearance 68) Enable Interlocking Parts 69) Maximum Angle for Unsupported Overhang 70) Available Infill Patterns 71) Active Cooling Extrudate 72) Hot/Cold Pause Ability 73) Requires Support Structure 74) Cathode Type 75) Vacuum Pressure 76) Material Supply Format/Packaging 77) Noise (Operation/Preparation/Idle) 78) Laser Wave Length 79) Material Deposition Mechanism 80) Number of Print Heads 81) Filament Diameter 82) Stepper Motors 83) Build Plate Material 84) Nozzle Heat Up Time 85) Build Plate Heat Up Time 86) Build Speed 87) Platform Leveling Mode 88) Laser Class/Certification 89) Peel Mechanism 90) Resin Fill Mechanism 91) Extruder Heater Cartridge Wattage/Voltage 92) Firmware Name/Version 93) Deposition Rate 94) Special Facility Requirements 95) Network Connectivity 96) Automatic Material Recognition 97) Internal Lighting 98) Enclosed Build Envelope 99) 3rd Party Material Compatible 100) Nozzle Offset X/Y/Z 101) Coordinate System 102) Printer Geometry 103) Coordinate System Origin 104) Absolute/Relative Density 105) Cytotoxicity (ISO 10993-5) 106) Melting Point 107) Magnetic Permeability 108) Electrical Resistivity 109) Specific Heat Capacity 110) Coefficient of Thermal Expansion 111) α/β Transus Temperature 112) Micro Vickers Hardness 113) Macro Rockwell C Hardness 114) Thermal Conductivity 115) Flexural Modulus/Strength 116) Tensile Modulus/Strength 117) Elongation at Break 118) Impact Strength 119) Heat Deflection Temp 120) Viscosity 121) Shore Hardness 122) Dielectric Constant/Strength 123) Volume Resistivity 124) Flammability 125) Young's Modulus 126) Yield Strength and 127) Ultimate Tensile Strength.

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