A METHODOLOGY TO DEVELOP ONTOLOGY OF ADDITIVE MANUFACTURING USING FORMAL ATTRIBUTES SPECIFICATION TEMPLATE (FAST)

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) with Honours. The member of the supervisory committee is as follow

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This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Design) with Honours

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ABSTRACT

Additive Manufacturing offers design creativity and freedom in product developing process. As a result, large number of design information is generated and accumulated. This resulting a time consuming for designer in searching the right information. In this project the additive manufacturing processes have been classified according to their attributes and an ontology of additive manufacturing is developed. Ontology allows the designers to obtain knowledge from previous method to be shared and reused for future references. The key point in developing the AM ontology is the combination of Formal Concept Analysis (FCA) and attribute that is obtained using a systematic guidelines called Formal Attributes and Specification Template (FAST). The attributes are characterized in terms of its mereological and topological structure and its involvement with one or more processes. FAST express the formal attributes in terms of: (1) inputs (a.k.a objects that are always changed by the process); (2) outputs (a.k.a objects that are always produced by the process); (3) participating physical objects (including locations, agents, and performer) other than inputs and outputs; (4) sub-activities (a.k.a sub-activities that compose the process). FCA is a method based on applied lattice and order theory, is selected as the taxonomy generator (class hierarchy).The developed class hierarchy was evaluated by homogeneous cluster analysis. The results of evaluation show that FAST method allow the finding of similarities between classes.

ABSTRAK

Additive Manufacturing adalah teknologi yang memberi peluang kreativiti dan kebebasan dalam proses menghasilkan produk. Ini telah menyebabkan pengumpulan data yang terlalu banyak. Berikutan itu, mencari informasi yang mengambil masa yang lama. Dalam projek ini proses additive manufacturing telah di kelaskan mengikut ciri setiap proses dan ontology telah dibina. Ontology dibina adalah untuk membolehkan ilmu atau pengetahuan daripada kaedah yang telah digunapakai terhadap proses-proses terdahulu dapat dikongsikan dan diguna semula untuk rujukan di masa hadapan. Kunci kepada penghasilan AM ontology adalah dengan kombinasi kaedah Formal Concept Attributes (FCA) dan Formal Attributes Specification Template (FAST). Ciri-ciri proses telah dikelaskan mengikut merelogi dan struktur topologi dan kaitan antara suatu proses dengan proses yang lain. FAST mencirikan kelas mengikut kriteria (1) input (objek yang sentiasa berubah megikut proses); (2) outputs (objek yang sentiasa dihasilkan oleh proses); (3) fizikal objek yang terlibat (termasuk lokasi, agen dan pelaku) selain daripada input dan output, (4) sub-aktiviti (sub-aktiviti yang membantu proses utama). Kaedah FCA yang menghasilkan lattice dan teori susunan telah digunakan sebagai taxonomy generato untuk pembinaan kelas hierarki. Pembinaa kelas hierarki kemudiannya di nilai melalui homogeneous cluster analysis. Keputusan penilaian telah menunjukkan FAST dapat membantu dalam mencari ciri yang sama antara kelas.

DEDICATION

Dedicated to my father, Mohd Hashim b. Ayob and my mother Shandi bt Ngah Ahmad, beloved brother and sister, friends and most of all to my supervisor without whom this project would have been completed within a year.

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Design
FCA	-	Formal Concept Analysis
SL	-	Stereolithoghraphy
SGC	-	Solid Ground Curing
BPM	-	Ballistic Particle Manufacture
DMLS	-	Direct Metal Laser Sintering
FDM	-	Fused Deposition Modeling
SLS	-	Selective Laser Sintering
3DP	-	3 Dimensional Printing
TSF	-	Topographic Shape Formation
LOM	-	Laminated Object Manufactured
DM	-	Desktop milling
HIS	-	Holographic Solidification Interference
SFP	-	Solid Foil Polymerization
PLT	-	Paper Lamination Technology
EBM	-	Electron Beam Melting

DED	-	Direct Energy Deposition
MASON	-	Manufacturing Semantic Ontology
FAST	-	Formal Attributes Specification Template

CHAPTER 1
INTRODUCTION

1.1 Background

There are two ways of manufacturing methods for creating a physical object, subtractive and additive manufacturing process. The subtractive manufacturing process is the traditional process which involves a removal of material. An example of the process are milling, drilling, and boring. While additive manufacturing (AM) is another method of manufacturing process that involves the latest technologies in which part are produced by adding layer-by-layer deposition of material. AM offers a geometrical freedom, such as design complexity, part consolidation, parts customization and material combination for each part production. The additive manufacturing cycle consists of geometric creation using modeling modeler, determination of suitable deposition orientation, slicing, generation of material deposition paths, part deposition and post processing operations (Thrimurthulu et al., 2003).

In order to develop the Ontology of Additive Manufacturing the classification of each process is necessary and important to obtain the information and characterize the potential process classes. AM consist of four categories; (1) powder bed process, (2) material deposition process, (3) 3D printing and (4) liquid. Each category is only suitable for certain AM methods. As an example, powder bed processes category is for the laser sintering (LS) , laser melting (LM) and electron beam melting (EBM) methods which do not involve the blown powder or extrusion process. Gibson et al. (2010) found that Pham (1998) made a comprehensive two dimensional classification method based on earlier documented process classification made by Kruth (1991). The first dimension refers to the method by which the layers are constructed. The earlier development of AM technology is a single point source which is implemented to draw across the surface of base material. Then the system has developed a new method by adding the sources in order to increase the throughput example are 1D, 2x1D, array of 1D channel and 2D channel. However, this classifications results in numerous dissimilar processes that are grouped together. Also, this work added material as a new factor for further classification and improvement. The method proposed by Pham (1998) is lacking of the deposition of composite material using and extrusion based system as the material is excluded in their data. As with many classification there can be sometimes processes or system that lie outside them. (Gibson et al., 2010)

The classification of these processes were keep changing from time to time parallel with the evolution of CAD technology. Therefore, the proper classification data of AM process is required in order to enable the designer have the advantage of design creativity and freedom of AM in which it faster the product development time.

Recently, the use of ontologies for managing the information and knowledge of AM has been reported in literature. Ontology is one approach to the computer representation of processes, it captured the semantics of things represented in specific domain which compose of classes represent a set of things that share the same attributes (Akmal & Batres, 2013). It is popular in engineering knowledge modeling and retrieval for its overwhelming searching ability than exact-match searching method (Liu et al., 2010). It has been used for the last decades for a set of tasks such as improving communication between agents (human/software) or reusing data model or knowledge schema. All these tasks deal with the capability of being used or operated reciprocally and can be applied in different domains. Consequently, ontologies have evolved and several kinds of ontologies have been proposed in different field (Roussey, 2011). Several ontologies have been developed for generic knowledge representation for example PRONTO, MASON and ADACOR.

In developing and ontology-based for redesigning process plans in AM, Liu and Rosen(2010) suggest that the knowledge modeling techniques support the application from three aspects ; (1) design feature ontology , (2) representation of manufacturing rules and (3) redesign flow of process planning. The key idea is that a new process plan under new manufacturing requirement could be obtained by modification of certain variables of the current process. Therefore, in this project, a methodology to develop AM ontology using a systematic guideline of formal attributes characterization and formal concept analysis is proposed.

1.2 Problem statement

There are numerous ways to classify AM technologies. A popular approach is to classify according to baseline technology, like whether the process uses lasers, printer technology, extrusion technology, etc. Another approach is to collect processes together according to the type of raw material input (Gibson et al., 2010). The problem with these classification methods is that some processes get lumped together in what seems to be an odd combination and there is no clear representation of data that can be understand and access by the user easily. Example like Selective Laser Sintering being grouped together with 3D printing or that some processes that may appear to produce similar result end up being separated (Gibson et al., 2010). Therefore, in order to have a better data classification for additive manufacturing, a formal concept analysis (FCA) is used. Formal concept analysis is a technique for knowledge processing that is based on applied lattice and order theory.

1.3 Objective

1. To classify the additive manufacturing processes according to their processes attributes
2. To develop an ontology of additive manufacturing using the combination of formal concept analysis and a set of process characterization.

1.4 Scope

In developing this ontology for additive manufacturing a formal concept analysis (FCA) will be used in order to obtain the functional system required. The FCA concepts can be partially ordered into a lattice, which a main concepts subsumes another concept. Lattice concept will be generated by using a proper algorithm. From that a context table can be generated which allow to determine the subclass and attribute of a system. The attributes stated in this research according to the relationship between additive manufacturing process, material and the channel use to distribute the layer. Resulted from the data, a class hierarchy will be develop and convert it into a computer-processable form by using Protégé ontology editor. Protégé will facilitates the specification of classes, relation and axioms. Then, OWL language is used to save the ontologies which will be useful for automatic reasoning and integration.

CHAPTER 2
LITERATURE REVIEW

2.1 Additive Manufacturing

2.1.1 What is additive Manufacturing

Additive layer manufacturing, or rapid prototyping, rapid manufacturing, layered manufacturing, direct digital manufacturing, solid free form fabrication, digital manufacturing and freeform fabrication are the other names that can be used to represent the additive manufacturing. AM is a process of producing a product by receiving a 3D CAD data from any design software which then will be converted into an STL file before sending it to the machine for fabrication. This usually involves an addition of material layer by layer. Gradually AM technology has simplified the process of manufacturing complex design, as using a 3D CAD system will enable the model to be fabricated without any need for process planning (Gibson et al., 2010). In other manufacturing processes a detail of process planning must be made. Several factors must be taken into consideration such as analysis of part geometry to identify the critical point, what additional fixtures need to be designed to complete the part, and what tools should be used throughout the whole process. Figure 2.1 shows the product development cycle of manufacturing.

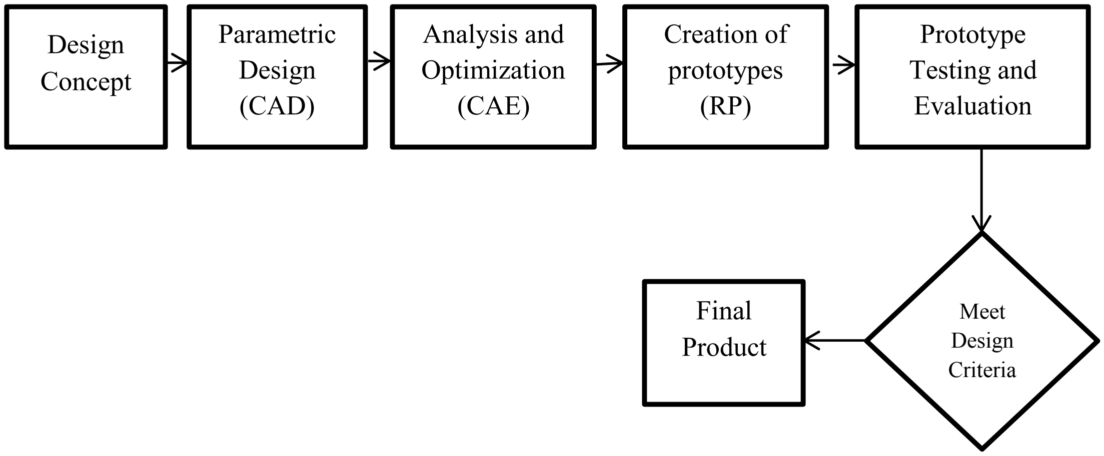

Figure 2.1 : Product Development Cycle **(Noorani, 2006)**

Additive manufacturing processes are gradually expanding through growing interconnection in between networks of machine, manufacturing lines, cells, plants or enterprises and also enhanced by the massive development in CAD/CAM technologies. This process has been a benchmarked of flexible automation and it has incredibly reduced the design cycle time to produce an intricate product (Srivastava et al., 2014). Figure 2.2 shows the seven (7) steps of requirement for Additive Manufacturing.

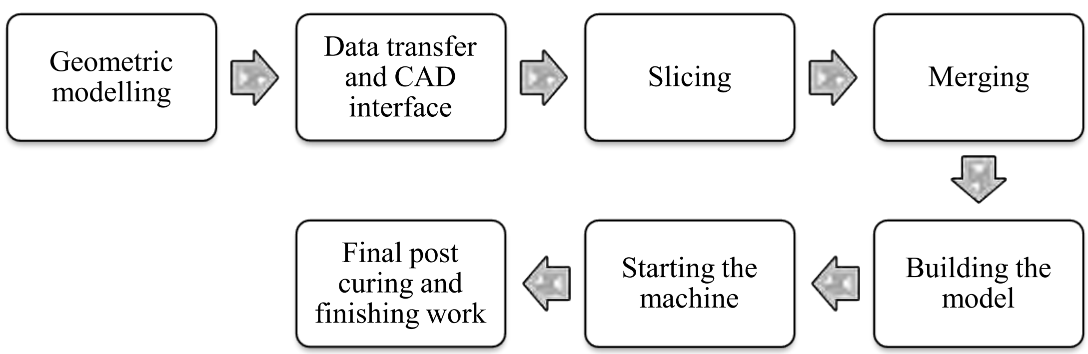

Figure 2.2 : Additive Manufacturing step requirement **(Srivastava et al.,2014)**

Some classification has been made according to their similar attributes, for example base on their technology, whether its user laser or extrusion or another example of classification