Design and Development of the Rapid Prototyping Techniques Ontology with the Appropriate Technique Selection Approach

Nasibeh Pouti

April 27, 2022

Design and Development of the Rapid Prototyping Techniques Ontology with the Appropriate Technique Selection Approach

Nasibeh Pouti
Information Technology and Computer Engineering Department
Sayyed Jamaleddin Asadabadi University
Asadaabad-Hamedan-Iran
Email: pooti.np@sjau.ac.ir

Abstract---**This article aims to design and develop Rapid Prototyping Techniques Ontology based on the study of new generation web as the Semantic Web that is a method of encoding and retrieval of information will be able to understand and process the information. To create an ontology that makes up the backbone of the Semantic Web, first, the selective techniques of rapid prototyping systems were studied, and in the operating area of the appropriate technique, knowledge was extracted with the content analysis method. The output of this process is the ontology of rapid prototyping techniques that are fully covered knowledge in a given area with more than 600 axiom, 120 classes and sub-classes, and more than 60 features. In addition to a knowledge-based view in the field of selector systems of Rapid Prototyping, opens a new arena. In the end, domain knowledge using the owl language in the Protégé application is implemented as Rapid Prototyping Ontology.**

Keyword---Rapid Prototyping Techniques, Ontology, Selector System, Semantic Web

I. INTRODUCTION

The Semantic Web is a new architecture for the global web, combining traditional web content with a formal, machine-understandable meaning. The main motivation for creating the Semantic Web was to increase automation, web information processing, and improve interactions and collaboration between information systems. In essence, the Semantic Web is a set of languages and tools for the automated processing of information stored on the Web. The information provided on the Semantic Web must be fully dynamic to take full advantage of the capabilities of the Semantic Web. Therefore, semantic presentation of data and dynamics are the two main features of the Semantic Web. The Semantic Web can be thought of as a global space of intelligent machine computing in which all books, sciences, encyclopedias, and databases are put together meaningfully and with the ability to understand a concept that is not only human-understandable. It can also be understood and processed by a machine [1]. One of the goals of the semantic web is to provide a better knowledge management system in which knowledge is organized in a conceptual space based on its meaning, automated tools support data retention by checking inconsistencies and extracting new knowledge Keyword-based searches are replaced by semantic searches, and it is also possible to query from multiple documents [2].

To achieve these goals, a special architecture has been developed for the Semantic Web. This layered architecture on the web means that the top layer must be able to understand the lower layers and vice versa. Rapid prototyping techniques have been developed as new technologies in the field of manufacturing for about two decades. The multiplicity of these techniques, the variety of their characteristics, and the different industrial applications that use these techniques have made the issue of selecting the appropriate technique based on the characteristics for different applications a challenge [3]. Over the past two decades, a variety of decision-making, ranking, and prioritization methods have been developed to select the appropriate technique. However, due to the extensible nature of these techniques and the commercial systems developed based on them, the organization of knowledge in this field, which can be used as a knowledge base to select the appropriate technique based on the indicators used, has never been considered in these studies. While providing good potential for providing the knowledge needed to select the right system. Rapid prototyping techniques selection systems try to provide a new arena in the use of appropriate techniques in each application by developing capabilities and expanding applications.

Creating web-based selector systems with high availability and semantic exploration in the field of operation, which is accompanied by intelligence and the ability to understand feedback from another system, creates an ontology of these techniques with great attractiveness in production. . For this reason, this article, an attempt has been made to identify the metadata of this field of operation, to provide an ontology of rapid prototyping techniques as the cornerstone of a semantic web with the appropriate technique selection approach.

Considering the capabilities of ontology in presenting thematic and contextual knowledge, in this article, by analyzing the qualitative content of resources related to selecting the appropriate rapid prototyping technique as well as sources for identifying and introducing RP techniques, related categories were identified. Then, the categories in the form of entities-relationships formed the database of RP techniques, and by searching the database based on the categories, several important rules for selecting the appropriate RP techniques were extracted. Finally, using the process of creating an ontology, the ontology of these techniques was developed. The purpose of this study is to introduce the field of RP technology with the approach of selecting the appropriate technique to those interested in this field as a new paradigm in the field of industry.

II. RESERCH BACKGROUND

In this section, we will first have a brief overview of rapid prototyping techniques and selector systems, and then describe the structure of the semantic web and determine the position of the ontology.

A. Rapid prototyping

Rapid prototyping is the creation of a physical sample of computer design data by layer-by-layer deposition, without the use of tools. RP is a relatively new technology that was first commercially marketed in 1987 by 3D Systems, which is mainly used in manufacturing industries such as automobiles, aerospace, electrical appliances, etc. RP processes usually begin with a stereolithographic file, which describes a model created by a solid or surface code modeler. RP samples are used to view or approve designs to control the shape, fit, performance, or to create a tooling pattern for casting or modeling. Prototyping is a vital part of the product creation process that designers face. Rapid prototyping techniques, hereinafter referred to as RP, are new techniques in the field of prototyping and are techniques that can create physical prototypes using computer-aided design data [4] and be able to perform various evaluations and tests on the sample. Each RP system has its strengths and weaknesses, applications, advantages, and limitations, and the choice of the best system depends on many criteria. Some of these criteria are [5]: cost of purchasing and installing the system, device dimensions, sample dimensions, materials used to make the sample, type of laser used, laser power, laser beam diameter, etc. Due to the multiplicity of criteria and selection options for the proper application of these techniques, we need selector systems, some of which are listed in Table 1.

TABLE 1. PAST RP SELECTOR SYSTEMS

Researchers	Ability to rank	Use of language variables	Selection method	Criteria used for selection	Other features
Bauer et al. 1996 [6]	√	×	Benefit value analysis	Properties of materials	Calculation of construction time and hourly rate
Phillipson, 1997 [7]	√	×	Multi-criteria optimization	Cost, time, quality	Including hypothetical machines
Chuk and Thomson, 1998 [8]	√	×	Evaluation of weight criteria	Time, final smoothness, cost, mechanical properties, accuracy, surface finish, manufacturing chamber	Use quantitative and usable data provided to vendors
Bibb, 1999 [9]	×	×	Rule-based	Accuracy, wall thickness	Consider secondary tools
Masood and Soo, 2002 [10]	×	×	Rule-based	RP machine price, accuracy, surface smoothness, type of material, layer thickness, manufacturing space, manufacturing speed	Four selection options
Lan et al. 2005 [11]	√	√	Expert system integrated with fuzzy hybrid evaluation	Sample fabrication time, mechanical properties, surface finish, thermal properties, cost, dimensional accuracy, resolution and clarity, flexibility	Use of quantitative and qualitative data and pairwise comparisons based on expert opinions
Byun and Lee, 2005 [12]	√	√	Multi-criteria decision making, modified TOPSIS	Surface finish, overall dimensional accuracy, mechanical properties, cost, time	Use of quantitative and qualitative data
Mahesh et al. 2005 [13]	√	√	Fuzzy Logic	Surface finish, resolution and clarity, dimensional accuracy, mechanical properties	Use of quantitative data
Wilson and Rosen, 2005 [14]	×	√	Select decision support problem with a scenario and distance analysis	Complexity, build volume, resolution and sharpness, mechanical properties, time, cost	Suitable for use in situations of epistemological uncertainty
Rao and Padmanabha, 2007 [15]	×	√	Graph theory and matrix approach	Dimensional accuracy, cost, time, polishing and surface quality of the sample, mechanical characteristics	Use an 11-point comparison scale for quantitative and qualitative data
Armillotta, 2008 [16]	√	×	Multi-criteria decision making, hierarchical analysis	Sample functional characteristics, time, cost, mechanical properties, surface finish, dimensional accuracy, final finish	Use of pairwise comparisons, qualitative data
Lokesh and Jain, 2010 [17]	√	√	Multi-criteria decision-fuzzy hierarchical analysis	Accuracy, quality, time, and cost	Ability to choose between an unlimited number of systems
Chatterjee and Mukherjee [18]	×	√	Rule-based expert system	Material, sample size, accuracy, cost, overhead time	Outputs include fast production options, direct and indirect tools, and equipment
Munguia et al. 2011 [19]	√	√	Fuzzy inference	The resolution, surface finish, time, cost, mechanical properties, thermal properties, material type, manufacturing chamber, dimensional accuracy	Use of quantitative and qualitative data

Vahdani et al. 2011 [20]	√	√	Multi-criteria decision making, new modified TOPSIS	Surface finish, time, cost, overall dimensional accuracy, mechanical properties	Use of quantitative and qualitative data
Chakraborty, 2011 [21]	√	×	Multi-criteria decision making, MOORA method	Surface finish, elongation, tensile strength, time, cost, overall dimensional accuracy, mechanical properties	Use of quantitative data
Khrais et al. 2011 [22]	√	√	Fuzzy inference method	Manufacturing chamber, surface finish, quality, time, cost, overall dimensional accuracy, mechanical properties, final finish	Use of qualitative data and expert opinions, direct weight allocation
YT, 2012 [23]	√	×	Multi-criteria decision making, TOPSIS method	Surface finish, time, cost, overall dimensional accuracy, mechanical properties	Use of quantitative and qualitative data
Ghazy, 2012 [24]	√	√	Simple Multi-Attribute Ranking Technique (SMART)	Strength, hardness, density, wall thickness, accuracy, surface finish, thermal bending temperature	Has database modules, knowledge base, and user interface and advisor
Robertson et al. 2013 [25]	√	×	Suggested rating system	Cost, sample surface smoothness, time	Use of quantitative data
Taghavifard and Pouti, 2013 [26]	√	√	Multi-criteria decision making-fuzzy TOPSIS	Accuracy, layer thickness, resolution, machine and sample dimensions, power supply parameters, cost, structure, technology, scanning tool, operating system, the material used	Ability to choose between an unlimited number of systems
Mahapatra and Panda, 2013 [27]	×	√	Grey Relationship Analysis (GRA)	Overall dimensional accuracy, time, cost, mechanical properties, surface quality	Using Grey theory and fuzzy theory
Wang et al. 2013 [28]	×	√	Grey Relationship Analysis (GRA)	Surface finish, time, cost, overall dimensional accuracy, mechanical properties	Use of quantitative and qualitative data
Zhang and Bernard, 2014 [29]	√	√	Measuring the amount of knowledge	Surface finish, time, cost, overall dimensional accuracy, mechanical properties	Use of quantitative and qualitative data and direct weight allocation
Shende and Kulkarni, 2014 [30]	√	×	Multi-criteria decision making, using TOPSIS and graph theory	Bending temperature, construction time, accuracy, cost, tensile strength, elongation, surface finish	Use a few criteria in the first step and then complete the criteria by comparison and modeling

Liao et al. 2014 [31]	√	√	VIKOR and DEMATEL rankings and network analysis process	Reliability	Use of qualitative data of experts
Zhang and Bernard, 2014 [32]	√	×	Integrated decision model (similarity model-deviation model)	Cost, surface smoothness, time, mechanical properties	Use of analytics and quantitative and qualitative data
Kumar et al. 2016 [33]	√	√	Multi-criteria decision making, network analysis process	Cost, product quality, time, pollution control	Use network analysis instead of hierarchical analysis
Zheng et al. 2017 [34]	√	√	Design of uneven weight sets based on fuzzy axioms	Construction time, tensile strength, accuracy, sample cost, elongation, roughness, and surface roughness	Using the preferred graph method, preferential ranking flexibility based on the purpose of performance evaluation
Anand and inodh, 2018 [35]	√	√	Multi-criteria decision making, TOPSIS, and fuzzy hierarchical analysis	Strength, aspect ratio, speed, roughness and inequality, minimum size, separability, layer thickness, material adaptability, geometric complexity, cost	A limited number of alternatives and criteria
Zaman et al. 2018 [36]	√	√	Multi-criteria decision making, hierarchical analysis	Material type, process type, machine type, performance strength, tensile strength, flexibility in failure, surface finish, material cost, backup material cost	Based on the data of the three databases, it is first done based on the process, the machine, and the initial sieving materials
Wang et al. 2018 [37]	√	√	Multi-criteria decision-TOPSIS and hierarchical analysis	Sample surface characteristics, geometric characteristics, thermal and electrical properties, cost, time, resource status	Cover a large number of criteria, and use a combination method
Kadkhoda-Ahmadi et al. 2019 [38]	√	√	Multi-criteria decision making, a hierarchical analysis process	Technical and economic characteristics of the process, machine, and materials, time, accuracy, cost, and performance of prototype manufacturing	It consists of two phases: initial detection and screening based on process, machine, and material characteristics and then selection based on sample characteristics
Qin, et al. 2020 [39]	√	√	Multi-Criterion Decision Making, Combined	Accuracy, roughness, strength, elongation, cost, construction time	Ability to choose between an unlimited number of systems

			Capability Operators Benfroni Weighted by Fuzzy Archimedes Method		
Palanisamy, et al. 2020 [3]	√	√	Multi-criteria decision-making - the best and worst criteria	Construction volume, layer thickness, material type, model material, backing material, raw material, path tracking tool, machine size, advantages, technology, model material supplier, maximum material size, material change mode, final payment, final improvement, material option Digital, material waste, resume option, backup layers, RP software, machine access, accuracy, wall thickness, resolution, repeatability, 3D printing cost, chemical solvent, biodegradation	Ability to choose between an unlimited number of systems and a wide range of criteria
Chandra et al. 2022 [40]	√	√	hybrid MCDMapproach, SWARA and COPRAS methods	Material/Product Quality, Machine Performance, Market stability, Total cost, Ecological values	The study considers some important criteria, including energy consumption, eco-friendly and wastage-free production, that help Sustainable additive manufacturing
Tavcar, Nordin, 2021 [41]	√	×	Multi-criteria AM function (MCF)	Material, Quality grades, Cost	increase cost awareness in the conceptual design phase and support product developers in doing AM cost estimation and process selection
Ransikarbum, and Khamhong, 2021 [42]	√	√	Fuzzy Analytic Hierarchy Process and TOPSIS	Product characteristics, material characteristic, printer characteristic	Evaluating preferences from both technical expert and user groups

B. Semantic Web

The second part of the literature review is devoted to examining the structure of the Semantic Web. The purpose of semantic web development is to structure data, add its meanings, and ultimately represent knowledge with the help of machines using technologies and standards being developed and complemented by the World Wide Web Consortium. In the Semantic Web, machines (robots, servers, and computers) are supposed to be able to understand the contents of the Internet. In this structure, machines must be able to communicate with each other, not just humans.

C. Semantic Web Layered Structure

The structure proposed for the Semantic Web is a layered structure, in which we briefly examine each of the layers. The first layer, which includes "Unicode" and "URI", shows the texts and how to send them to the web. Unicode is an international standard (conforming to the ISO standard) for the exchange of multilingual information, Which assigns unique numbers to each letter, independent of the operating system environment, program, and language. "URI" stands for "Uniform Resources Identifier", a string of characters that indicates a location or address of a resource on the Internet, and from its components can be sufficient information about that resource, including the category of an object URI is used to define concepts in the Semantic Web[43]. The second layer, as a semantic web grammatical layer, includes the namespace, the expandable markup language, and the schematic of the expandable markup language. The namespace is a logical naming scheme for grouping related classes. This scheme prevents classes that use the same identifier for methods and properties from overlapping. Extensible Markup Language (XML) is a scripting language used to transmit structured data over the Internet, and is specifically designed to create web pages and is a continuation of HTML, but with the difference that the information in it is somehow stored and easily accessible and connected[44]. The third layer, the semantic web concept layer includes "RDF" and "RDF schema". The word "RDF" stands for "Resource Description Framework", a language based on "XML" used to describe concepts and create documents on the Semantic Web and gives meaning to the words of a page for search engines. Specifies the relationship between words. In other words, this language, using a set of mathematical and semantic relations, can form logical connections between data that can be addressed and directly accessible; But what makes it different from XML is that instead of tagging the inside of a document, external information about that document can also be tagged. "RDFS" is a semantic generalization of "RDF" and a word description language to further explain classes and groups of resources and their relationship, allowing resources to serve as examples of classes and subclasses. "RDFS" is similar to object-oriented languages and has characteristics such as class, features, etc. [45]

The fourth layer of the semantic web structure is the most important layer related to ontology. In the Semantic Web, the relationship between the concepts contained in Web documents is determined by concepts related to ontology. By doing this, machines can understand and process relevant documents and can communicate between them. Creating a common understanding of the terms used on the Web is one of the most important tasks of an ontology in a particular field. In other words, the ontology identifies the relationship between concepts in web documents and the real world, thereby making the relevant documents processable and understandable by machines, and facilitating sharing between agents. In the field of the

Semantic Web, an ontology shows the meaning of words and their relation to the field in which they are used. Various languages are used to build an ontology: OWL, which stands for Web Ontology Language, is the standard language introduced by WTC to build on-the-web, structure-based ontologies, and Web architecture is a family of languages used to model knowledge. Usually, such languages are used to design ontologies for AI issues. The purpose of OWL is to provide an XML encyclopedia of classes, their specifications, and the relationships between these classes and examples [46].

There are many tools for implementing an ontology, the most widely used of which is the Protégé. This software is a platform (has a development environment and a programming library that allows you to create an ontology in two ways manually or using code.) and open-source software (the ability to insert, update and component switching is available in this tool) to display knowledge based on an ontology developed by Stanford University School of Medicine. Protégé is a framework for building knowledge-based systems that enables the provision of a knowledge-based system based on RDF, OWL, and frame-based [47]. The fifth layer, as the "logic" layer, creates a clear framework and standard rules for inference engines tasked with generating ultimate knowledge on the Semantic Web. This layer, which is located above the ontology layer, is used to express intelligible expressions at the machine level. At the ontology level, the machine can understand the basic concepts of the semantic web, but to increase the semantic processing power of machines, it must be possible to define logical principles for them to use to infer. The logic layer uses rules that allow conclusions to be drawn from previous assumptions; In general, it determines a practical law if a series of conditions are met. The sixth layer of the semantic web to the subject "Proof" is assigned. After having intelligible regions for the machine, it is expected that different expressions can be proved with the help of logic. Logical expressions have value when they can be proved. The seventh layer, the "trust" layer, emerges using an electronic signature (a mathematical scheme for proving the identity and validity of a digital message or document); The web will only reach its full potential if users have confidence in the security of its operations and the quality of its information. In fact, despite the permission for anyone to make logical statements about sources, programs want to make only inferences based on statements they trust, so examining the source of the statements is a key part of the semantic web.

D. Ontology

An ontology is an explicit, accurate, and expressive representation of instances, concepts, and relationships in a subject area that, according to features such as inference, interconnection, and interoperability between information systems, support for natural language processing, search query understanding, etc. can be used to create intelligent information systems. An ontology is a semantic tool that incorporates common concepts and the consensus of experts in a subject area and uses rules and standards to describe the concepts and relationships between them. Providing common concepts as well as rules and standards in the ontology allows the exchange of information and the integration of scattered knowledge resources in different information systems. An ontology defines a common glossary for researchers who need to "share information" in a particular field and domain. This glossary includes machine-understandable definitions of the basic concepts of a domain and the relationships between them [56].

There are various reasons for the development of an ontology. Some of these reasons are: Sharing a common understanding of information structure between human or machine factors, the ability to reuse domain knowledge, separating domain knowledge from operational knowledge, and domain knowledge analysis. An ontology together with a set of individual examples of classes forms a knowledge base. In practice, there is a narrow boundary where the ontology ends and the knowledge base begins. Ontologies include descriptions of concepts, attributes, and their relationships. Concepts in the scope of the ontology are defined by classes. Attributes and connections called slots complement the concepts in the domain. More complex ontologies also include axioms and offer more complex methods for defining classes, such as creating constraints on specific attributes or counting class components, defining subclasses or separate classes, and so on. In practice, the development of an ontology involves the following steps: [48]

- Definition of classes in ontology
- Arrange classes in a "subclass-superclass" hierarchy
- Define slots and describe the values that these slots are allowed to have.
- Determine slot values for class instances

After these steps, the knowledge base can be created by defining individual instances of these classes, determining the specific values of the slots, and determining the additional constraints on the slots.

III. RESEARCH METHODOLOGY

In this paper, rapid prototyping techniques ontology is designed and created during the three phases, independent of the field used, which include data acquisition of the desired field, data classification and knowledge acquisition, design, and creation of the ontology.

A. Data acquisition

We have used the qualitative content analysis method to obtain data related to rapid prototyping techniques. This type of analysis has three approaches including conventional content analysis, directed content analysis, and summative content analysis. Conventional content analysis is commonly used in the design of studies that aim to describe a phenomenon and is often appropriate when existing theories or research literature on the subject are limited. Sometimes there are previous theories or researches about a phenomenon that is either incomplete or need further descriptions. In this case, the researcher chooses the method of content analysis with a directional approach. A study that uses a qualitative content analysis method with a summative approach begins with identifying and quantifying specific words or themes in the text, to understand how these words or their content are used in the text. This quantification is not only an attempt to understand the meaning of words but also seeks to discover the use of these words in the text. Table 2 compares these three approaches [49].

TABLE 2. BASIC DIFFERENCES IN CODING IN THREE CONTENT ANALYSIS APPROACHES

Type of content analysis	Start of research	Time to recognize codes or keywords	Origin of codes or keywords
Conventional Content Analysis	Observation	They are determined simultaneously with data analysis	Are derived from data
Directed Content Analysis	Theory	They are identified at the same time as or before the data analysis	Are derived from research theory or findings
Summative Content Analysis	Keywords	Keywords are defined before and during data analysis	Are obtained based on the researcher's interest or research literature

In this research, due to the nature of the research, the existence of a sufficient number of sources in the research literature, and the availability of guiding keywords, summative content analysis has been used. Based on the type of qualitative analysis and the selected method for extracting data from the documents, the content analysis protocol was created in the form of Table 3.

TABLE 3. QUALITATIVE CONTENT ANALYSIS PROTOCOL OF RESOURCES RELATED TO RP TECHNIQUES

1	Type of content analysis	Qualitative
2	References used	References related to the introduction of RP techniques and systems, resources related to the selection of the appropriate RP system
3	Type of sampling	A purposeful sampling of references
4	Approach	Summative content analysis
5	Perspective	Inductive content analysis
6	Analysis unit	Theme
7	Context unit	Paragraph
8	Coding protocol	1. Separation of keywords in the selection of rapid prototyping techniques 2. Study of resources related to each of the RP techniques and machines, 3. Separation of paragraphs containing one or more related themes, 4. Extraction of themes in the form of sentences 5. Extraction of content codes, 6. Combine codes and create categories

Qualitative content analysis was performed in two stages:

Step 1) At this stage, to identify topics related to RP techniques, 37 sources found in selecting the appropriate RP technique were reviewed. These resources contained key themes on the selection criteria and characteristics of RP techniques. In the study of this category of content analysis sources, the topics related to the selection criteria of RP techniques, which are the common features of most RP techniques, were identified.

Step 2) Considering that in the first stage, most of the resources focused only on the common features of RP techniques, therefore, to fully identify the techniques, it was necessary to examine the sources related to the introduction of each of the techniques. Thus, for each of the 50 identified systems of commercially common RP techniques, two sources were identified, themed, coded, and categorized.

Based on the analysis of summative qualitative content, the main categories related to RP techniques have been identified from references related to the characteristics of techniques and the determination of appropriate techniques. These categories are based on the obtained codes and their composition. Some of the categories extracted from RP sources are as follows.

- **RP machine categories**

The manufacturer of the RP machines, Some codes related to this category are Arkam, Stratasys, Soligen, Autostrade, EOSINT, Cubital, Generis, EAS, Kira, Solidscape, Miko, Optomek, etc.

The technology used by RP machines, which is one of the categories related to RP techniques, is created with codes such as technologies for making electron beam melting, melted sediment modeling, three-dimensional printing, lamination technique, and so on.

The structure of RP machines, Structure is a category that derives from the properties of RP techniques and is created through the codes of liquid, solid, and powder structure.

Workspace of RP machines, this category is derived from topics related to workspace features such as maximum workspace length (mm), which includes RP machines with a workspace length of between 100 and 1600 mm. Maximum width of the workspace (mm), which includes RP machines with a working space width of 100 to 800 mm. Maximum height of workspace (mm), which includes RP machines whose workspace height is between 60 to 1070 mm.

Accuracy of RP machines, accuracy is based on the dimensions of the workspace and depends on the user experience, skills, and other operational factors. It usually includes machines with an accuracy starting at 0.005 mm [50].

The thickness of the construction layer, less thickness creates a smoother surface but increases build time. Each RP machine has a spectrum for layer thickness. Depending on the part to be sampled, the user can select the maximum and minimum layer thickness. Includes systems with a construction thickness between 0.01 to 0.5 mm.

The material used by the RP system to produce samples, some these materials is EBS, resin, polyamide, nylon, metals, polystyrene, polycarbonate, polyphenyl sulfone, elastomer, LM sheet, composite, LM plastic, stretch, thermoplastic, ceramic, photopolymer, TSR resin, etc.

Construction speed in cubic (cm^3/h), this parameter indicates the ability of the RP machine to process, laminate, solidify or deposit materials and is not provided by the time of manufacture because then it will depend on many factors. This category includes construction speeds between 8 and 1575 cm^3/h.

Cost, which includes the cost of buying and installing an RP machine and is in dollars. This parameter varies between 50,000 $ and 680,000 $. In addition, it includes the cost of energy consumption and depreciation of the machine.

Scanning tools, RP machines use a variety of tools to build prototype layers. Some of these are [18]: high power ultraviolet lamp, solid-state semiconductor laser, neodymium YAG, helium-cadmium, carbon dioxide, incandescent pulleys with injection section, ink-jet print section, Electron beam, etc.

The dimensions of the RP system, including the length of the RP system, vary between 500 and 3660 mm. The width of the RP system varies from 430 to 3100 mm. The height of the RP system varies between 200 and 2900 mm. The weight of the RP system varies between 136 and 2540 kg.

Energy requirements, which are 6 parameters that determine the characteristics of the power supply. These parameters are the number of power supply which is a maximum of 3, the number of phases of the power supply which this parameter is 1 or 3. The maximum and minimum voltage of the power supply that these criteria vary between 12 to 460 volts, maximum amperage of the power supply which varies between 5 to 75 amps, frequency of the power supply which can be 50, 60, or 50/60.

The resolution of the RP machine includes the horizontal resolution (in the direction of X-Y) in millimeters. This criterion affects the quality and physical appearance of the sample made in the horizontal direction, the horizontal resolution of which starts from 0.01 and vertical separation (in the direction of Z) in millimeters, the minimum value of which is 0.05 in the vertical direction.

An operating system is a system that drives the software components of RP machines. The operating system can be one of the versions of Windows.

Contamination control by RP machine is one of the identified categories that result from codes such as gas emission, noise and vibration, waste disposal, recycling, chemical solvent, and biological decomposition.

- **RP sample categories**

The thermal properties of the sample, which include heat resistance, thermal bending temperature

The geometrical characteristics of the sample include the shape of the sample, the number of additional components and parts, the ductility and complexity of the sample.

Mechanical properties of the sample that are related to themes such as dimensional accuracy, size, flexibility, tensile strength, compressive strength, shear strength

Surface characteristics of the sample include the surface finish of the sample, surface roughness and roughness, surface clarity and resolution, tolerance, and surface accuracy.

The electrical properties of the sample include the electrical conductivity of the sample

Sample making time includes preparation times, sample preprocessing time, sample creation time, final sample payment time.

The cost of making a sample, which includes the cost of raw materials for the sample, the cost of backing materials used to create the sample, and the cost of using a 3D printer and the initial design of the sample.

B. Data classification and knowledge acquisition

There are several ways to categorize data. Some of these methods include decision tree-based methods, law-based methods, memory-based reasoning, neural networks, Bayesian theory-based methods, and support vector machines. In this application, law-based methods are used to acquire knowledge. To acquire rules, we need to categorize data so that we can extract rules by exploring and searching for data. To do this, we created a relational database. Database entities, as well as entity properties, were obtained based on the categories extracted from qualitative content analysis, and then the desired relationships were established between the entities. By examining the database created about RP techniques with the help of queries in the database tables, some rules about the features of RP machines have been obtained, some of which are as follows. Table 4 also shows some of the characteristics of RP techniques [51] [50] [43]:

- All RP techniques have only one main structure, liquid, solid, or powder
- Each RP model has at least one RP machine
- The thicker the sample fabrication layers, the more accurate the machine
- The higher the resolution of the machine, the higher the quality of the sample made
- The dimensions of the car manufacturing chamber are directly related to the dimensions of the sample
- The dimensions of the machine are directly related to the dimensions of the machine housing

- Every manufacturer has at least one RP car model
- Machines can only use one structure in terms of the main structures of solid, liquid, and powder
- Each RP machine has at least one type of raw material to build.
- Each RP machine has at least one scan tool
- Some RP machines have a cooling system
- Some RP machines have additional operations
- Some RP machines have colored raw materials
- Solid and powder-based systems require adhesives along with the raw material
- The output of RP machine software in all machines is in three forms: code, STL, and SLI
- Some fast prototyping machines require a backup structure
- Machines with backup structures prepare the final sample more slowly
- Some RP machines require additional sample operations
- Machines that perform sample finishing operations have a longer process for sample production
- Machines that perform complementary operations produce higher quality samples
- Some machines require a scanning system, which is a set of scanning tools

TABLE 4. SOME FEATURES OF RP TECHNIQUES

RP Machine	Model	Scan tools(Scan system)	Structure
SLA 3500	SLA	The laser system, Nd: YVO4 (laser + mirror + lens)	Liquid
SLA 5000	SLA	The laser system, Nd: YVO4 (laser + mirror + lens)	Liquid
SLA 7000	SLA	The laser system, Nd: YVO4 (laser + mirror + lens)	Liquid
Viper Si2	SLA	Dual beam laser system	Liquid
LOM-1015Plus	LOM	Carbon dioxide laser with roller drive system	Solid
LOM-2030H	LOM	Carbon dioxide laser with roller drive system	Solid
Vanguard si2 SLS	SLS	Carbon dioxide laser + powder distributor roller	Powder
EOSINT P 360	EOS	Carbon dioxide laser + dual laser system + powder lift system	Powder
MEM-250-II	MEM	Raw material lamination system + sheet heating part + wax or melted thermoplastic injection	Solid
M-RPMS-II	MEM	Raw material lamination system + sheet heating part + wax or melted thermoplastic injection	Solid
EOSINT M250 Xtended	EOS	Carbon dioxide laser + dual laser system + powder lift system	Powder
Solider 4600	SGC	High power ultraviolet lamp	Liquid
FDM 3000	FDM	Raw material pulley + melt part + injection part	Solid
Solider 5600	SGC	High power ultraviolet lamp	Liquid
FDM Maxum	FDM	Raw material pulley + melt part + injection part	Solid
EOSINT S	EOS	Carbon dioxide laser + dual laser system + powder lift system	Powder
SCS-1000HD	SCS	Helium-cadmium laser + galvanometric mirror	Liquid
SCS-2000	SCS	Solid-state semiconductor laser + galvanometric mirror	Liquid
SCS-3000	SCS	Solid-state semiconductor laser + galvanometric mirror	Liquid
SCS-8000	SCS	Solid-state semiconductor laser + galvanometric mirror	Liquid
FDM Titan	FDM	Raw material pulley + melt part + injection part	Solid
SSM-600	SSM	Raw material lamination system + sheet heating part + wax or melted thermoplastic injection	Solid
SSM-1600	SSM	Raw material lamination system + sheet heating part + wax or melted thermoplastic injection	Solid
EOSINT P700	EOS	Carbon dioxide laser + dual laser system + powder lift system	Powder
Z 400 3DP	3DP	Horizontal and vertical movement system for feeding powder and glue + printing system	Powder
Dimension	FDM	Raw material pulley + melt part + injection part	Solid
Z 406 3DP	3DP	Horizontal and vertical movement system for feeding powder and glue + printing system	Powder
SOUP II 600GS-02	SOUP	Solid state ultraviolet laser + resin level controller	Liquid
SOUP II 600GS-05	SOUP	Solid state ultraviolet laser + resin level controller	Liquid
SOUP II 600GS-10	SOUP	Solid state ultraviolet laser + resin level controller	Liquid
Prodigy Plus	FDM	Raw material pulley + melt part + injection part	Solid
Z 810 3DP	3DP	Horizontal and vertical movement system for feeding powder and glue + printing system	Powder
R4	R	Ink jet + feed small droplets of glue	Powder
LENS 750	LENS	Nd:YVO4 laser with one scan head + laser focusing part + powder delivery opening	Powder
LENS 850	LENS	Nd:YVO4 laser, dual + laser focusing part + powder delivery opening	Powder
ModelMaker II	Model Maker	Ink jet + wax adhesive + cutting additional parts	Solid
KSC-50N	PLT	Laminating system + hot press system	Solid
DSPC 300	DSPC	Powder injection section + electric adhesive droplet injection section + distributor roller	Powder
PLT-A4	PLT	Sheet cutting system + hot press system	Solid
LC-510	LC	Helium-cadmium laser + NC controller	Liquid
PatternMaster	Model Maker	Ink jet + wax adhesive + cutting additional parts	Solid
E-Darts	E-Darts	Semiconductor laser + vertical motion system	Liquid
MJS	MJS	Powder melt head with vertical movement + interchangeable injection section with horizontal movement	Powder
ThermoJet Printer	Thermo Jet	Thermojet as power supply + X-Y locomotor system	Solid
ARCAM EBM S12	EBM	Melt electron beam + vacuum tank + vacuum generating pump + control unit	Powder
GS 1500	GS	Horizontal and vertical movement system for feeding powder and glue + printing system	Powder
R 10	R	Ink jet + feed small droplets of glue	Powder
SOLIFORM 250B	SOLIF ORM	Solid-state laser + fixed and variable beam diameter + laser control system	Liquid
SOLIFORM 250EP	SOLIF ORM	Solid-state laser + fixed and variable beam diameter + laser control system	Liquid
SOLIFORM 500C	SOLIF ORM	Solid-state laser + fixed and variable beam diameter + laser control system	Liquid
SOLIFORM	SOLIF	Solid-state laser + fixed and variable	Liquid

500EP	ORM	beam diameter + laser control system	

Criteria with value for each RP machine are machine dimensions, construction chamber dimensions, accuracy, resolution in horizontal and vertical directions, manufacturer, manufacturing technology, machine model, machine operating system, machine power supply parameters, scanning tools, materials.

C. Design and creation of ontology

- **Ontology.** In recent years, the development of ontologies - as a formal and explicit description of terms in a particular domain and the relationships between them [52] - has evolved from laboratory work in artificial intelligence laboratories to a work in real applications.
- **Ontology components.** An ontology together with a set of individual examples of classes forms a knowledge base. In practice, there is a narrow boundary where the ontology ends and the knowledge base begins. Ontologies include descriptions of concepts, attributes, and their relationships. Concepts in the scope of the ontology are defined by classes. Attributes and connections called slots complement the concepts in the domain. More complex ontologies also include axioms, which are called axioms, and offer more complex methods for defining classes, such as creating constraints on specific attributes or counting class components, defining subclasses or separate classes, and so on.

In practice, the development of an ontology involves the following steps [53]:

• Definition of classes in ontology

• Arrange classes in a "subclass-superclass" hierarchy

• Define slots and describe the values that these slots are allowed to have.

• Determine slot values for class instances

After these steps, the knowledge base can be created by defining individual instances of these classes, determining the specific values of the slots, and determining the additional constraints on the slots.

IV. ONTOLOGY OF RAPID PROTOTYPING TECHNIQUES

Since the background knowledge required to select the appropriate rapid prototyping technique includes a broad set of relationships and interactions between parameters, the development of an ontology for sharing background knowledge, analyses related to the adoption of the appropriate technique to the application. To achieve this goal, it is necessary to go through 5 steps [54]: determining the scope and domain of the ontology, considering the issue of reusing the ontology, counting the important words in the ontology, defining class hierarchy, defining class properties.

A. Determining the scope and domain of the ontology

The domain in question in this ontology is all the rapid prototyping techniques that are used commercially. Because these techniques are implemented by RP machines, the ontology for rapid prototyping techniques needs to cover all aspects of identifying dimensions, capabilities, applications, parameters affecting the sample, and identifying existing RP machines. In addition, what increases the attractiveness of knowledge in this field is the ability to adapt the application to the appropriate RP system, which turns the ontology into an application-oriented ontology.

B. Consider the issue of reusing ontologies

Considering what has already been done by others and making changes, modifications, or extensions to existing resources to suit our particular scope and the specific application is a worthwhile process. Reusing existing ontologies is essential when the system in question requires interaction with other application systems that have used a particular ontology (or a specific glossary)

C. Counting important words in the ontology

At this stage, it is useful to make a list of all the words we want to explain in one application. Because in the next steps, it helps us to identify classes and subclasses and attributes and connections. Some important words in this field are: prototyping-rapid prototyping systems-construction dimensions-accuracy-quality-layer thickness-resolution-scanning tool-power supply-laser-resin-liquid-based systems, solid and powder-scanning speed-purchase, and installation cost-UV lamp-polyamide-polystyrene-SLA-LAM-SCS-3D company-COLAM-FDM company-composite sheet-thermojet-inkjet, etc.

As can be seen, by extracting some words related to prototyping techniques, the way is paved for the next step, which is to categorize the concepts and create a class-subclass hierarchy. Of course, among the words, in addition to concepts, there are also attributes, relationships, and examples that are distinguished in the next steps.

The next two steps involve developing the hierarchy of classes and defining the properties of very closely intertwined concepts. In such a way that it is very difficult to distinguish between them and to consider the precedence and lag between them. We usually start by defining a limited number of concepts in the hierarchy and then move on to describing their characteristics (created concepts). These steps are the most important in the ontology design process.

D. Definition of classes and class hierarchy

There are different approaches to the development of class hierarchies:

• Top-down approach: The top-down development process begins with the definition of general concepts in the domain. It then continues the development process by creating more specific subclasses of these concepts.

• Bottom-up approach: The bottom-up development process begins with the definition of very specific classes, the leaves of the class hierarchy, then continues the development process by grouping these classes into more general concepts.

• Hybrid approach: Hybrid development process is a combination of top-down and bottom-up methods. In this method, first, prominent and important concepts are defined. Then, with the generalization (combination) or privatization (analysis) of these concepts, the development process continues.

A top-down approach has been used to develop an ontology of rapid prototyping techniques. From the list we created in step three, select the words that describe the independent objects. In ontology, these words define "class" and form anchor points in the hierarchy of classes. Classes are placed in a hierarchical pattern. This hierarchical pattern is formed on the basis that if an object is an instance of one class, will it be an instance of another class? And if so, these classes are in a class-subclass hierarchy. Otherwise, they will be separate classes. If we pay attention to the words, we see that in the field of rapid prototyping techniques, two main concepts can be designed and identified. One is rapid prototyping systems and the other is built-in prototypes, and the other terms are related to these two terms. Each of the two main concepts is defined as a superclass. There are several other concepts related to the concept of rapid prototyping systems, which we call RP machines, which are defined as the relevant subclasses. Some of these subclasses are machine dimensions, manufacturing chamber dimensions, resolution, the thickness of fabric layers, power supply, scanning speed, scanning tool, manufacturing material, machine accuracy, machine cost, etc. Each of these subclasses, in turn, has other subclasses, and we continue the class-subclass definition process until the next level is objects or instances.

The next superclass is a sample that has subclasses such as time-cost-quality-size, etc. These subclasses can be extended to several levels to fully cover the concept.

One way to identify subclasses of a class is that the class-subclass hierarchy should be such that the sample defined for the last subclass is also an instance of the subclasses associated with that subclass. Figure 1 shows a class-subclass hierarchy of rapid prototyping techniques developed in Protégé software version 4.2.2.

E. Define class properties

Classes alone do not contain enough information to answer competency questions that test the ontology's ability to respond to background knowledge. In addition, by extracting some related domain words, and assigning them to the class and subclass hierarchy, several words remain, which are attributes and examples. For each attribute in the list (remaining words) we must specify which class describes it. It should be noted that all subclasses of a class inherit the characteristics of the main class. In addition, each of the subclasses includes other unique features in addition to the main class features. Features are basically of two categories [52]:

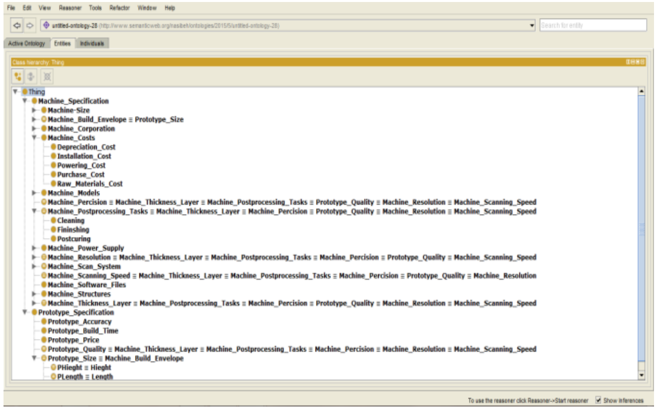

Fig 1. View of RP techniques classes and subclasses

• Data properties that specify the relationship between an instance or object with data values

• Object properties that determine the relationship between two classes or two objects.

Figure 2 shows some of the ontological features of rapid prototyping techniques.

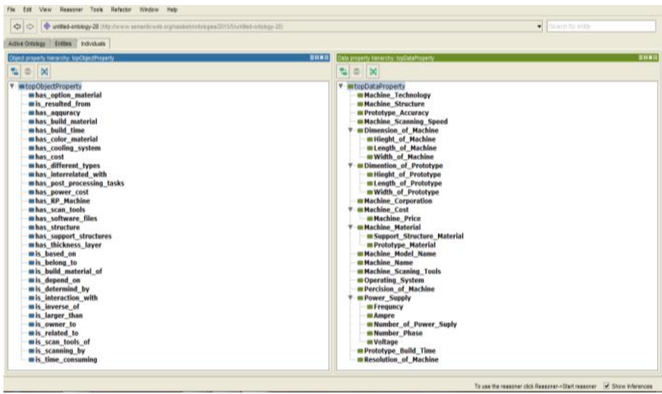

Fig 2. An overview of the data and object properties of RP techniques.

Some data properties include:

Prototype-Material, Prototype-Accuracy, Machine-Structure, Machine-Model-Name, Operating-System, Machine-Technology, …..

Some of the object properties are:

has-power-cost, has-thickness-layer, is-time-consuming, is-larger-than, is-scan-tools-of, has-post-processing-task,…….

Given the definition of the original structure, we can now create the extracted rules. For example, one of our rules was that every RP machine is based on one type of raw material:
Related classes: Machine Structure-Machine Material
Related property: is-based-on

As can be seen in Figure 3, using restrictions, firstly, only one structure is acceptable for each machine, and secondly, the machines of each structure are disjoint with the other two structures. In this figure, examples of materials used in the solid structure are also observed.

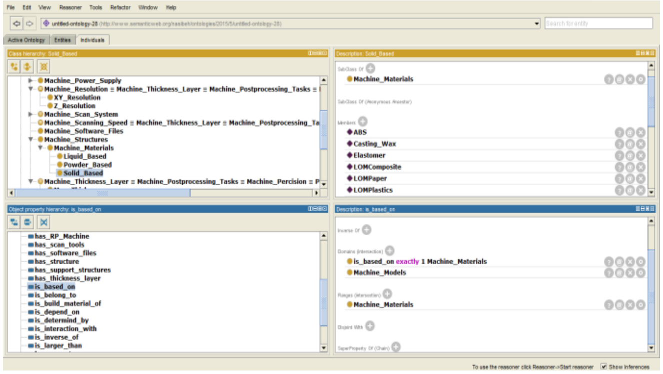

Fig 3. Creating an axiom using cardinality and quantity limiters

Another restriction of the quality of the sample is that according to the rules derived from library studies, it depends on the accuracy, resolution, complementary operations, scanning speed, and thickness of the RP machine layers (Figure 4).

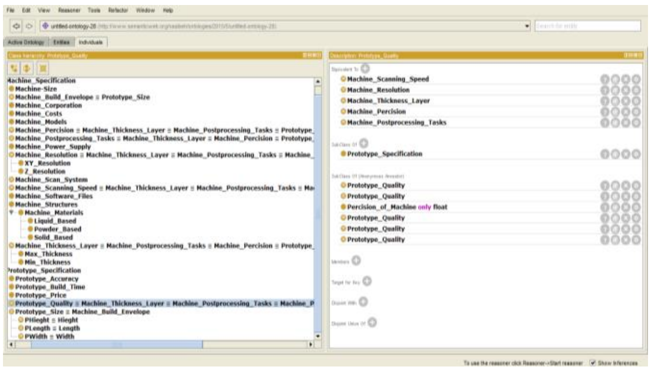

Fig 4. Creating an axiom using class descriptors

Finally, we define the relevant object for the final subclasses. In the subclass description section, the objects are introduced as members of the subclass. Figure 5 shows the members of the FDM model subclass as an object.

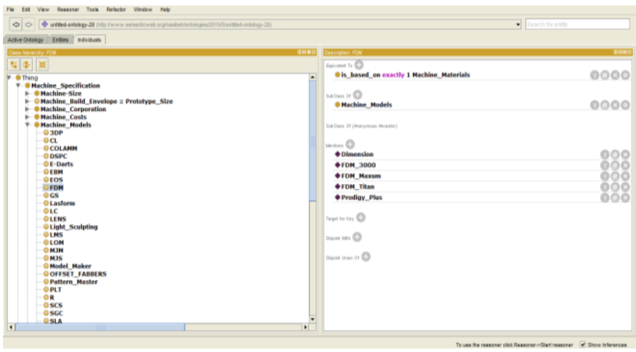

Fig 5. Introducing subclass objects using member descriptors

Figures 6 and 7 show a graphical view of the ontology created using OWLViz and ontoGraph, two of the most powerful graphical tools in Protégé software.

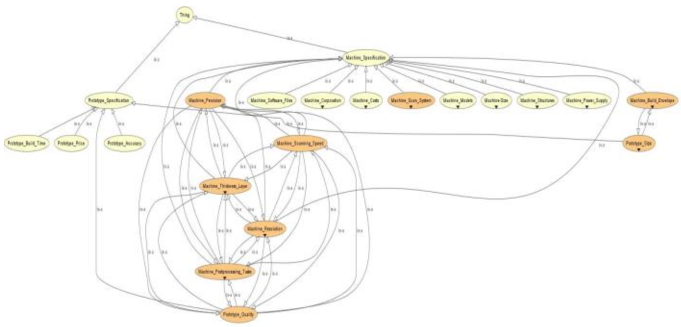

Fig 6. OWLVis view of the RP technology ontology

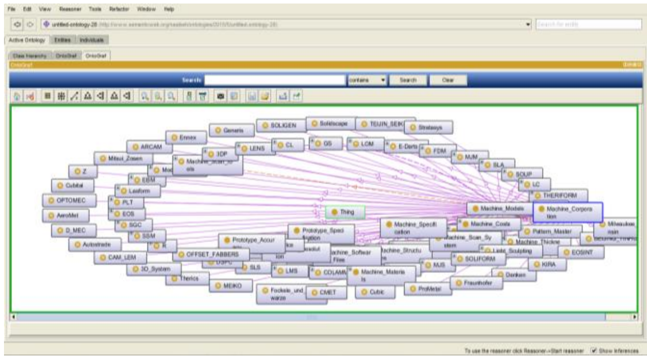

Fig 7. OntoGraph view of the RP Technologies ontology

In addition, the ontoGraph tool also provides graphical search capabilities. For example, Figure 8 shows a graphical search for the word cost in this ontology.

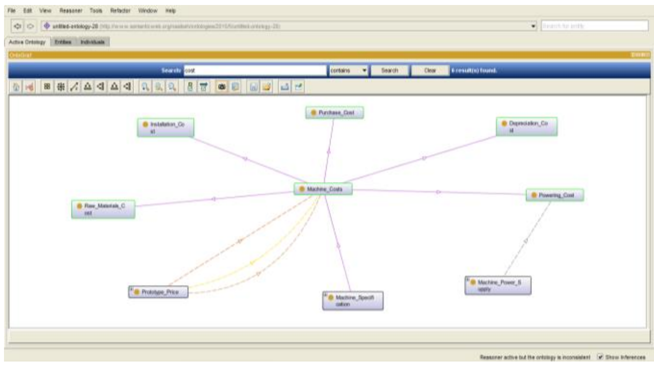

Fig 8. Graphic search on cost entity in ontoGraph

The Protégé tool, which is an ontology design tool, is based on the OWL language, which is a powerful language for describing metadata, and all parameters entered in the software can be retrieved in the OWL language.

Figure 9 shows an ontology created in OWL that begins with the definition of namespaces. Finally, Figure 10 shows the statistics of ontology entities (class-subclass-data property-thematic property-axioms-types of limiters, type of thematic properties, etc.)

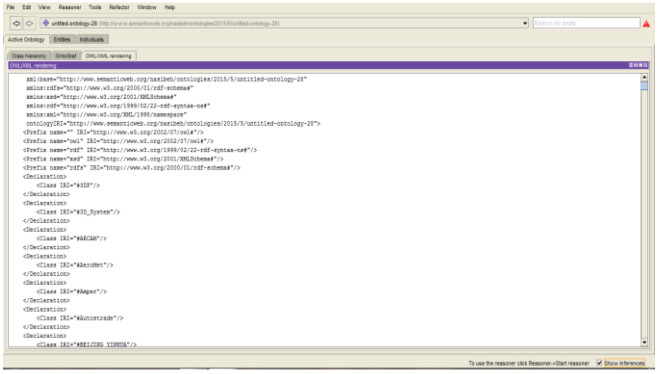

Fig 9. An overview of the OWL RP technology ontology

V. CONCLUSIONS AND SUGGESTIONS

More than two decades have passed since the advent of rapid prtotyping technology, or in other words, additive manufacturing, but due to the emergence of new technologies and techniques in this field, selective systems are still studied in several ways. But based on a review of more than a decade of selective systems studies, no studies have yet sought to establish an ontology-based structure with the appropriate technique selection approach. This study is an innovation in systems that select this technology. Most studies have focused on criteria, decision-making methods and modeling [55], but the creation of such a structure is a new issue in this area.

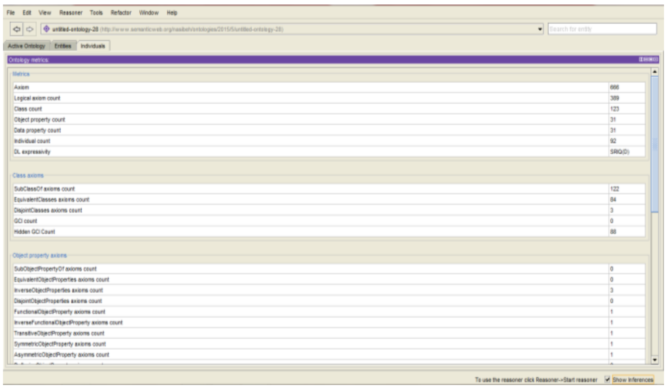

Fig 10. An overview of inventory statistics for RP techniques

In this article, new RP techniques in the industry to develop ontology and ontology of these techniques have been studied. To develop the ontology of data and information related to these techniques, two groups of sources have been extracted by qualitative content analysis method, which includes resources related to providing the appropriate technique identification method and sources introducing techniques and their characteristics. About 50 RP systems were identified and their characteristics were determined based on the content of the resources and then the knowledge related to these techniques was structured based on the stages of ontology development. Based on this, suggestions for future research are recommended as follows:

Considering that one of the important issues in the field of knowledge of fast prototyping techniques and also the use of these techniques is the selection of the appropriate technique, and based on the literature review in this field, there is a real gap in the use of data mining techniques, it is recommended In future research, various data mining methods should be used to extract knowledge in this field. Of course, one of the difficulties of data mining in this field is to access the data of samples made by any type of RP machine, which is the reason for the lack of data mining research in this field. Methods such as using the decision tree to create rules can have good potential for future research. Especially considering that many selective systems of the past have also used law-based expert systems.

Another suggestion that could have the potential for future research is to use a variety of intelligent systems such as artificial neural networks to model the optimal fan selection, which in this case also requires data from previously created samples, and this can be one of Also being considered limitations or challenges.

Due to the purpose of this study, which was to identify the field of RP technology, and also this knowledge had the orientation of choosing the appropriate technique, there were some challenges and limitations in conducting research, such as limiting the identification and use of resources for qualitative content analysis. In this area, an attempt has been made to cover the resources related to the selection of the appropriate technique during the last two decades. They were satisfied.

REFERENCES

[1] T. Berners-Lee, J. Hendler, O. Lassila, “The semantic web“. Scientific American, Vol.284, No.5, pp. 34-43, 2001.

[2] P. A. Bonatti, S. Decker, A. Polleres and V. Presutti, “Knowledge graphs: New directions for knowledge representation on the semantic web” (dagstuhl seminar 18371). In Dagstuhl Reports (Vol. 8, No. 9). Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik, 2019.

[3] C. Palanisamy, N. Chinnasamy, K. Muthu, ”Influence of Process Parameters on Rapid Prototype Part Using Response Surface Methodology”. Journal of Engineering Technology and Applied Physics. 1. pp. 4-7. 10.33093/jetap.2019.1.2.

[4] C. K. Chua, “Three–dimensional rapid prototyping technologies and key development areas”, 2011.

[5] C. K. Chua, K. F. Leong and C. S. Lim, “Rapid Prototyping Principles and Application”, Nanyang Technological University, Singapore, 2004.

[6] J. Bauer, H. H. Klingenberg, H. Müller, “Computer based rapid prototyping system selection and support”. Proceedings of time compression technologies conference, The Heritage Motor Center, Gaydon, UK, pp 241-250, 1996.

[7] D. K. Phillipson, “Rapid prototyping machine selection program”. The 6th European conference on rapid prototyping and manufacturing, Nottingham, UK,1997, pp. 292-303.

[8] R. N. Chuk, V. J. Thomson, “A comparison of rapid prototyping techniques used for wind tunnel model fabrication”, Rapid Prototyping Journal 4 (4), pp.185-196, 1998.

[9] R. Bibb, “The development of a rapid prototyping selection system for small companies. Thesis”, School of Product Design and Engineering, University of Wales Institute, Cardiff, 1999.

[10] S. H. Masood, A. Soo, "A rule-based expert system for rapid prototyping system selection". Robot Computer Integr Manuf, Vol. 18, pp. 267-274.
[11] H. Lan, Y. Ding, J. Hong, "Decision support system for rapid prototyping process selection through the integration of fuzzy synthetic evaluation and an expert system". International Journal of Production Research, Vol. 43, No. 1, pp.169-194, 2005.
[12] H. S. Byun, K. H. Lee, "A decision support system for the selection of a rapid prototyping process using the modified TOPSIS method", International Journal of Advanced Manufacturing Technology 26 (11-12):1338-1347. doi:10.1007/s00170-004-2099-2, 2005.
[13] M. Mahesh, J. Y. Fuh, Y. Wong, H. T. Loh, "Benchmarking for decision making in rapid prototyping systems". In: Automation Science and Engineering, 2005. IEEE International Conference on, 2005. IEEE, pp. 19-24.
[14] J. O. Wilson, D. Rosen, "Selection for rapid manufacturing under epistemic uncertainty". In: ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 2005. American Society of Mechanical Engineers, pp. 451-460.
[15] R. V. Rao, K. Padmanabhan, "Rapid prototyping process selection using graph theory and matrix approach". Journal of Materials Processing Technology, Vol. 194, No.1, pp. 81-88, 2007.
[16] A. Armillotta, "Selection of layered manufacturing techniques by an adaptive AHP decision model", Robotics and Computer-Integrated Manufacturing 24 (3):450-461. doi:10.1016/j.rcim.2007.06.001.
[17] K. Lokesh, P. K. Jain, "Selection of Rapid Prototyping Technology", Advances in Production Engineering & Management, Vol. 5, No. 2, pp. 75-84, 2010.
[18] D. Chatterjee, B. Mukherjee, "Study of Fuzzy AHP Model to search the criterion in the evaluation of the best technical institutions", International Journal of Engineering Science and Technology, Vol.2, No.7, pp. 2499-2510, 2010.
[19] J. Munguia, A. Bernard, M. Erdal, "Proposal and evaluation of a KBE-RM selection system". Rapid Prototyping Journal, Vol.17, No.4, pp. 236-246, 2011.
[20] B. Vahdani, S. M. Mousavi, R. Tavakkoli-Moghaddam, "Group decision making based on novel fuzzy modified TOPSIS method". Applied Mathematical Modelling, Vol.35, No.9, pp. 4257-4269, 2011.
[21] S. Chakraborty, "Applications of the MOORA method for decision making in a manufacturing environment", The International Journal of Advanced Manufacturing Technology 54 (9-12), pp.1155-1166, 2011.
[22] S. Khrais, T. Al-Hawari, O, Al-Araidah, "A fuzzy logic application for selecting layered manufacturing techniques". Expert Systems with Applications, Vol. 38, No. 8, pp. 10286-10291, 2011.
[23] Ic. YT, "An experimental design approach using the TOPSIS method for the selection of computer-integrated manufacturing technologies", Robotics and Computer-Integrated Manufacturing, Vol. 28, No. 2, pp. 245256, 2012.
[24] M. M. Ghazy, "Development of an additive manufacturing decision support system (AMDSS) ". Newcastle University, 2012.
[25] D. Roberson, D. Espalin, R. Wicker, "3D printer selection: A decision-making evaluation and ranking model". Virtual and Physical Prototyping, Vol.8, No.3, pp. 201-212, 2013.
[26] M. T. Taghavifard, N. Pouti, "Design and development of decision support system for ranking rapid prototyping techniques and selecting the best technique in the automotive industry", Information Technology Management, Vol.15, No.2, pp. 1-32, 2013.
[27] S. S. Mahapatra, B. N. Panda, "Benchmarking of rapid prototyping systems using grey relational analysis". International Journal of Services and Operations Management, Vol. 16, No. 4, pp. 460-477, 2013.
[28] P. Wang, P. Meng, J-Y. Zhai, Z-Q. Zhu, "A hybrid method using experiment design and grey relational analysis for multiple criteria decision-making problems". Knowledge-Based Systems, Vol.53, pp. 100-107, 2013.
[29] Y. Zhang, Y. Xu, A. Bernard, "A new decision support method for the selection of RP process: knowledge value measuring". International Journal of Computer Integrated Manufacturing, Vol.27, No. 8, pp. 747-758, 2014.
[30] V. Shende, P. Kulkarni, "Decision Support System for Rapid Prototyping Process Selection", International Journal of Scientific and Research Publications, Vol.4, No.1, 2014.
[31] S. Liao, M-J. Wu, C-Y. Huang, Y-S. Kao, T-H. Lee, "Evaluating and Enhancing Three-Dimensional Printing Service Providers for Rapid Prototyping Using the DEMATEL Based Network Process and VIKOR". Mathematical Problems in Engineering, 2014.
[32] Y. Zhang, A. Bernard, "An integrated decision-making model for multi-attributes decision-making (MADM) problems in additive manufacturing process planning". Rapid Prototyping Journal, Vol.20, No.5, pp. 377-389, 2014.
[33] V. Kumar, L. Kumar, A. Haleem, "Selection of Rapid Prototyping Technology Using an ANP Based Approach", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) Vol.13, No.4 Ver. VI (Jul. - Aug. 2016), pp. 71-78.
[34] P. Zheng, Y. Wang, X. Xu, Sh. Quan Xie, "A weighted rough set based fuzzy axiomatic design approach for the selection of AM processes". International Journal of Advanced Manufacturing Technology, Vol.91, No.5-8, pp. 1977-1990, 2017.
[35] M. B. Anand, S.Vinodh, (2018) Application of fuzzy AHP-TOPSIS for ranking additive manufacturing processes for microfabrication, RapidPrototyp. vol. 24, no.2, pp. 424–435, 2018.
[36] U. K. Zaman, M. Rivette, A. Siadat, S. M. Mousavi, "Integrated product-process design: Material and manufacturing process selection for additive manufacturing using multi-criteria decision making", Robotics, and Computer-Integrated Manufacturing, Vol. 51, pp.169–180, 2018.
[37] Y. Wang, R. Y. Zhong, X. Xu, "A decision support system for additive manufacturing process selection using a hybrid multiple criteria decision-making method", Rapid Prototyp Journal, Vol.24, No.9, pp. 1544–1553, 2018.
[38] S. Kadkhoda-Ahmadi, A. Hassan, E. Asadollahi-Yazdi, "Process and resource selection methodology in design for additive manufacturing", International Journal of Advanced Manufacturing Technology, https://doi.org/10.1007/s00170-019-03991-w, 2019.
[39] Y. Qin, Q. Qi, P. Scott, J. Jiang, "An additive manufacturing process selection approach based on fuzzy Archimedean weighted power Bonferroni aggregation operators". Robotics and Computer-Integrated Manufacturing. 2020 Aug 1; 64. 101926. https://doi.org/10.1016/j.rcim.2019.101926.
[40] M. Chandra, F. Shahab, K. E. K. Vimal, S. Rajak, "Selection for additive manufacturing using hybrid MCDM technique considering sustainable concepts". Rapid Prototyping Journal, 2022.
[41] J. Tavcar, A. Nordin, "Multi-Criteria assessment and process selection model for additive manufacturing in the conceptual phase of design". Proceedings of the Design Society, 1, pp.2197-2206, 2021.
[42] K. Ransikarbum, P. Khamhong, 2021. "Integrated fuzzy analytic hierarchy process and technique for order of preference by similarity to ideal solution for additive manufacturing printer selection". Journal of Materials Engineering and Performance, Vol.30, No.9, pp.6481-6492, 2021.
[43] S. Yasodha, Pudukkottai, "An ontology-based framework for Semantic Web Content Mining", International Conference on Computer Communication and Informatics, pp. 1-25, 2014.
[44] A. Gyrard, C. Bonnet and K. Boudaoud, "Domain knowledge Interoperability to build the Semantic Web of Things", 2014.
[45] M. Lenzerini, L. Lepore, A. Poggi, "Making meta querying practical for Hi(DLLiteR) knowledge bases, in On the Move to Meaningful Internet Systems": OTM 2014 Conferences, 8841, pp. 580–596.
[46] W. Gao, M. R. Farahani, A. Aslam, S. Hosamani, "Distance learning techniques for ontology similarity measuring and ontology mapping" Cluster Computing, Vol. 20, No. 2, pp. 959-968, 2017.
[47] C. Verma, V. Mahadevan, N. Rasiwasia, G. Aggarwal, R. Kant, A. Jaimes, S. Dey, "Construction and evaluation of ontological tag trees". Expert Systems with Applications, Vol.42, No.24, pp.9587-9602, 2015.
[48] S. Shekarpour, E. Marx, "Semantic interpretation of user queries for question answering on interlinked data", Web Semantics Journal, Vol 30, pp. 39-51, 2015.
[49] H. F. Hsieh, S. E. Shannon, "Three approaches to qualitative content analysis". Qualitative health research, Vol.15, No.9, pp.1277-1288, 2005.
[50] S. K. Lee, G. Mogi, M. Koike, K. S. Hui, J. W. Kim, "Fuzzy Integrated Analytic Hierarchy process approach for selecting strategic big-sized R&D programs in the sector of energy technology development", FUZZ-IEEE 2009, Korea.

[51] S. Lepreux, C. Kolsky, G. Queric, ”Towards a Methodology for DSS user-centered Design”.Wiley and Blackwell, 2003.

[52] A. Maedche,”Ontology Learning for the Semantic Web”, Kluwer Academic Publisher, 2002.

[53] J. Davies, D. Fensel, and F. Van Hrmelen “Towards the Semantic Web: Ontology-Driven Knowledge Management”, New York: Wiley, 2003.

[54] N. F. Noy, M. Sintek, S. Decker, M. Crubézy, R. W. Fergerson, M. A. Musen, ”Creating semantic web content with protege-2000”. IEEE intelligent systems, Vol.16, No.2, pp. 60-71, 2001.

[55] S. Jhunjhunwala, S. Kapil, ”Rapid Manufacturing of Biomedical Devices: Process Alternatives, Selection and Planning”. In Advanced Micro-and Nano-manufacturing Technologies (pp. 77-104). Springer, Singapore, 2022.

[56] K. Meng, C. Cui, H. Li, ”An ontology framework for pile integrity evaluation based on analytical methodology”. IEEE Access, Vol. 8, pp. 72158-72168, 2020.