Census and Analysis of Design Solutions of 3D Replicating Rapid Prototyper (RepRap)

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Recently, a new manufacturing process known as rapid prototyping has received a significant attention for the capability of producing accurate parts directly from CAD models. For the purpose, many techniques have been developed and can be divided broadly into those involving the addition of material and those involving its removal. Fused Deposition Modeling is the most widely technique used in additive manufacturing (AM) due to its low unit cost. This paper presents an implementation of a methodology for census and classification of different technical solutions used in a diversity of recent 3D printers including mechanical links, guiding system components, motion transmission equipment, fused deposition modeling system, stepper motors, thermistors, sensors, Electronics Board, open source firmware and software, fused deposition materials and others.

Keywords— CAD/CAM, Replicating Rapid Prototyper RepRap, Additive layer manufacturing, FDM.

I. Introduction

The Rapid Prototyping is an innovative manufacturing technology that has distinguished from others machining manufacturing processes by the ability of obtaining products without involving cutting tools, fixturing and other associated activities [1]. Known by several other names such as digital fabrication, 3D printing, solid free form fabrication, layer based manufacturing, laser prototyping, free form fabrication, and Additive Manufacturing (AM), the process involves building of parts series or prototypes in a relatively short time to help create and test various, ideas, design features, concepts, functionality and in certain instances outcome and performance. The basic principle Additive Manufacturing technology is that a model, initially generated using a three-dimensional Computer Aided Design (3D CAD) system, can be fabricated directly without the need of process planning. This process may be classified according to the technology used for the growth of the part. Mention may be made in this regard, stereolithography, laser sintering, fused deposition modeling, solid ground curing, and laminated object manufacturing [2, 3]. Among these techniques, Fused Deposition Modeling is the most widely used due to its low unit cost and still then the most popular of them all [4, 5, 6]. 3D printers that run on FDM Technology build parts layer-by-layer by heating thermoplastic material to a semi-liquid state and extruding it through a computer-driven extrusion nozzle [7]. FDM uses two materials to execute a print job: modeling material, which constitutes the finished product, and support material, which acts as scaffolding. Material filament is fed from the 3D printer's material nozzle head, which moves in X and Y axes, depositing material to complete each layer before the base moves down in the Z axis, and then, the next layer begins. Once the 3D printer is done building, the user breaks the support material away or dissolves it in detergent and water, and the part is ready to use. 3D printers are self-replicating rapid prototypers (RepRaps), which can print approximately half of their own mechanical components from sequential fused deposition of a range of polymers and use common hardware [8]. The RepRap is a mechatronic device consisting of printed mechanical components, stepper motors, sensors, thermistors, a hot-end for melting and depositing sequential layers of polymers, printbed and so on. All electronic components are controlled by an open-source micro-controller such as the Gen6 Deluxe or the Arduino Mega 2560. The extruder intakes a filament of the working material (polydactyl acid (PLA), acrylonitrile butadiene styrene (ABS)), melts it using resistive heating, and extrudes it through a hot-end nozzle. Actually, 3D machines are now about to upset the world of conventional manufacturing processes, and many other domains extensions. From a social point of view, this open source held great promise for development of appropriate technologies to help millions of world's poorest communities reach a better standard of living. But in return, from a technical development trend, the mass of data constantly sharing, on the RepRap, by this large developers and designer's community, makes that hardware and software are in perpetual-accelerated improvement and it's of a great benefit to reach project maturity. Nowadays, a wide range of several open sources 3D printers are published in the web, namely Prusa, Huxley, MakerBot, Wallace, Protos, MendelMax, and others types. Although these all 3D Self-Replicators share the basic function "fused deposition of material", they differ in manner how technical integrated-solutions to concretize this end and also by the limitation of implemented solutions (accuracy, build-time, complexity of parts geometry, difficulty of assembling the various components of the machine, maintainability…). Thus, the objective of this paper is to present an implementation of a methodology for census and classification of different technical solutions used in 3D printers open source's design: mechanical

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links, linear slider system of motion axis, fused deposition modeling system, stepper motors, heat-beds, bearings, electronics boards, open source firmware and software, fused deposition materials and others…. By a detailed analysis and rigorous comparison of different technical solutions (advantages and disadvantages), we plan, in the future, to develop an new design of a 3D RepRap, ensuring manufacturing and management of optimal parameters while maintaining a competitive price.

II. STATE OF ART

The first generation design of RepRap that is used to make copies of its own rapid prototyped parts is the "Darwin" version. It is a stepping-motor-driven Cartesian robot consisting of an open cubical frame made from M8 threaded steel rods, held together by printed parts and M5 screws. An MDF flat build platform upon which parts are made, moves in the Z axis in that frame, driven on screw threads by a NEMA 17 stepper motor. The MDF build plate has eight M8 nuts attached at its corners which are driven up and down by four M8 threaded bars synchronized by a timing belt. The nuts are in pairs held apart by springs to eliminate backlash. The horizontal X and Y axes are driven directly by toothed timing belts and two more NEMA 17 stepper motors. The machine prints layer by layer to form a solid object by extruding a thin stream of molten plastic through a nozzle to form each layer. The build base then moves one increment down, the second layer is extruded, and so on. In the end of the process, the part is removed manually.

The second generation design is the "Mendel". The Mendel's shape resembles a triangular prism rather than a cubical like the Darwin frame. This second improved version has many key improvements over Darwin. The Mendel has a bigger print area, simple to assemble, lighter and more portable. Constraint on the z-axis are improved to eliminate jamming by using only two threaded rods, M8 nuts, one NEMA 17 stepper motor, a timing belt and pulleys that serve to move vertically the print platform. The X and Y axis are more efficient thanks to linear ball bearing. The latest versions of Mendel are the Prusa Mendel, the MendelMax 2.0, and the RepRapPro Mendel. The main difference between these versions to the old version of Mendel is that the two threaded rods required to move the print platform in the Z axis are trained directly by two NEMA 17 stepped motors. Two coupling that can be printed clamps or shaft coupling are used to couple the stepper motors axes with the threaded rods.

The third generation design is officially named "Huxley". Huxley is a Mini-Mendel with some re-designed parts based on a miniaturized version of the Mendel hardware with 30% of the volume of those for Mendel, which is to say it could reproduce three times faster. The machine uses NEMA 14 stepper motors, M6 threaded rods, M6 nuts, and bolts contrary to Mendel that uses 8M threaded rods and M6 nuts. Mendel can print itself, and so Huxley. In addition, the idea was to develop both Mendel and Huxley in parallel, with Huxley being as cut-down and minimal as possible, and Mendel being the machine with all the fancy capabilities. Huxley is the fastest replicator, while Mendel is the most versatile. The latest version of Huxley is named RepRapPro Huxley, in which two M5 threaded rods, two M5 nuts, and four printed clamps, ensure movement of the heated bed platform. The machine is controlled by Melzi controller board, and trained by four NEMA 17 stepped motors and one NEMA 14 stepper motor that train the drive screw of the extruder.

Nowadays, a wide range of 3D printers that differ in term of mechanical components and undercarriages exists. However, the concept of a platform moving horizontally in the X and Y axis, and on the Z axis vertically is same. Other versions are radically different such as the Orion Delta, Rostock Max, which are maturing slowly and have an initial working solution for experimentation, by self-sourcing builders of some experience. The main difference between the Delta and Rostock and other version, is that the extruder system moves in the X, Y, and Z axes, and a build platform upon which the part is built is immobile. These versions use aluminum bars and delta arms cheapskate bearings, effector platform, instead of threaded rods, nuts, smooth rods and linear ball bearing.

III. FONCTIONAL ANALYSIS

Functional Analysis is a systematic approach that provides a technical and educational method that is part of a rational approach for construction of knowledge and know-how, and provides sufficient reference to analyze, select and use an equipment, whatsoever and whatever technological developments are foreseeable or not. The purpose of the FA is to optimize the design or redesign of a 3D printer based on the functions it must perform. 3D machine fills a specific function that responds to the need for a user itself, and conditioned by various factors (technical, economical, regulatory, sociological ...). The determined function is divided into sub - functions increasingly simple ones, which will provide technical solutions. These functions are defined in terms of aims without any priori solutions. The diversity of technical solutions can determine the extent of the choice of devices having the same overall function. During this process of functional analysis, we followed the steps presented in chronological order which follow:

- Needs Analysis
- Functional Needs Analysis
- Technical Functional Analysis

A. *Needs analysis*

Analysis of need can express the need met by 3D machine. Often project participants prefer the known solutions without the need for concrete analysis that justifies the project. Before imposing a solution, we must turn to the user, to achieve a structured way to the solution, because a project makes sense only if it meets the need. It is therefore to express the need at the outset of the project. So, it is required to explain the fundamental requirement that justifies the design or redesign of a 3D printer. To do that, it is essential to ask the following three questions:

- For whom, for what, a 3D machine makes service?
- To whom, to what, the machine acts?

- For what purpose?

The answers to these three questions lead to a statement of need, which should be written as follows:

The 3D printer renders service to the user by allowing him to print 3D objects by acting on the raw material.

The representation of need can be outlined through a graphical tool called the “horned beast” which is presented in Fig.1.

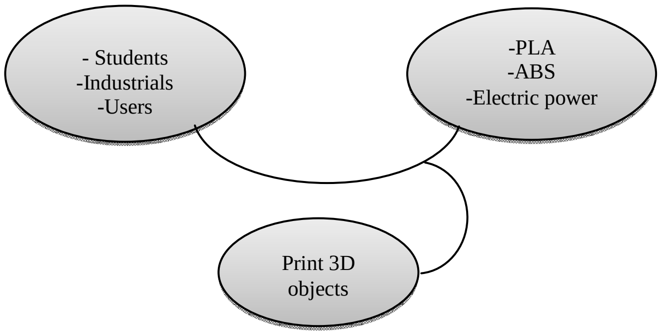

Fig. 1. Hornet beast that expresses the need

B. *Functional Needs Analysis*

Functional Needs Analysis will allow us to identify the relationship of 3D printer with its context of use, in order to identify features that should satisfy the need. The research method of functions is based on the following principles:

In each phase of its life cycle, the 3D machine will be in direct contact with an outside element. It is therefore necessary first to describe its environment by determining all elements outside the machine that will be in contact with it. These external features in the use phase of life of the 3D printer are; the user, electricity, a platform on which the machine will be putted, the environment, the computer, and the CAD file of the part to manufacture.

Once the elements of the external environment are defined, we look for the relationship between the elements of the external environment and the 3D machine. Whenever it is possible to express a service, there will be a service function. Service functions can be classified into two types, main functions and stress functions. A main function is released when a relationship exists between two elements or more of the external environment with the machine. A stress function is released when an item from the external environment has an action on the machine.

After a careful analysis, the main function and stress functions found in the use phase of the 3D printer lifecycle are:

MF1: Print 3D CAD part designed by the user, and generated by a 3D CAD modeler, via computer

SF1: To connect to a computer

SF2: To resists attacks from the outside environment

SF3: To put on a platform

SF4: To be Adapted to the energy source

SF5: To prevent the user from burn hazard

The elements of the external environment and all relations between these elements and the 3D printer are represented in a graph of interactors known as the “Octopus”, which is shown in Fig.2.

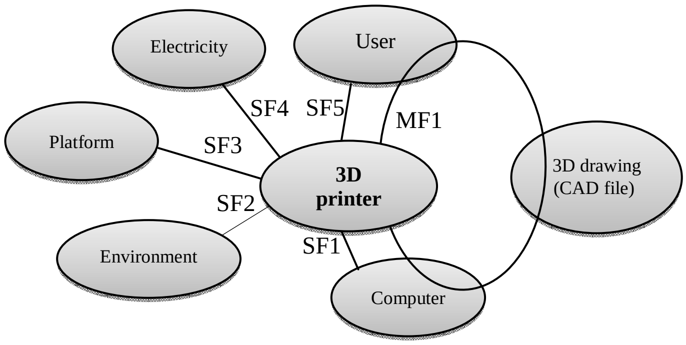

Fig. 2. Otopus diagram

It is notable that the Functional Analysis of Need focuses on the functions of the product design. It does prejudge neither induced technical functions nor constructive solutions that will be sought at the stage of Technical Functional Analysis.

C. *Technical Functional Analysis*

The Technical Functional Analysis is a method that will allow us to determine the technical functions necessary to perform the main function and stress functions. These technical functions will guide us in the search for technological solutions. For this, we used the diagram known as the "Function Analysis System Technique" (FAST). FAST diagram is built from left to right, in logic of why to how. Thanks to its technical and scientific culture, we developed the service functions of the 3D machine, to technical functions to choose solutions in order to finally build the machine. By applying this approach to the machine, the FAST diagram obtained is shown in Fig.3.

IV. CIRCUS AND CLASSIFICATION OF DIFFERENT TECHNOLOGIES USED IN 3D PRINTERS

To find technical solutions that fulfill the service functions, we examined reference products similar to that we want to design. This is very useful to control, locate the analysis already conducted, possibly identifying forgotten function, and then improve the design. In this context, we studied nineteen versions of 3D printers and we summarized the technical solutions used to meet the service functions. In this paper, we compared for some versions of 3D printers, technological solutions used to fill in sub-functions of the following function, which consists in ensuring the kinematic to depose the first layer of material and ensuring the deposition of the next layer.

A. *Ensure the kinematic to depose the first layer on a platform of the machine*

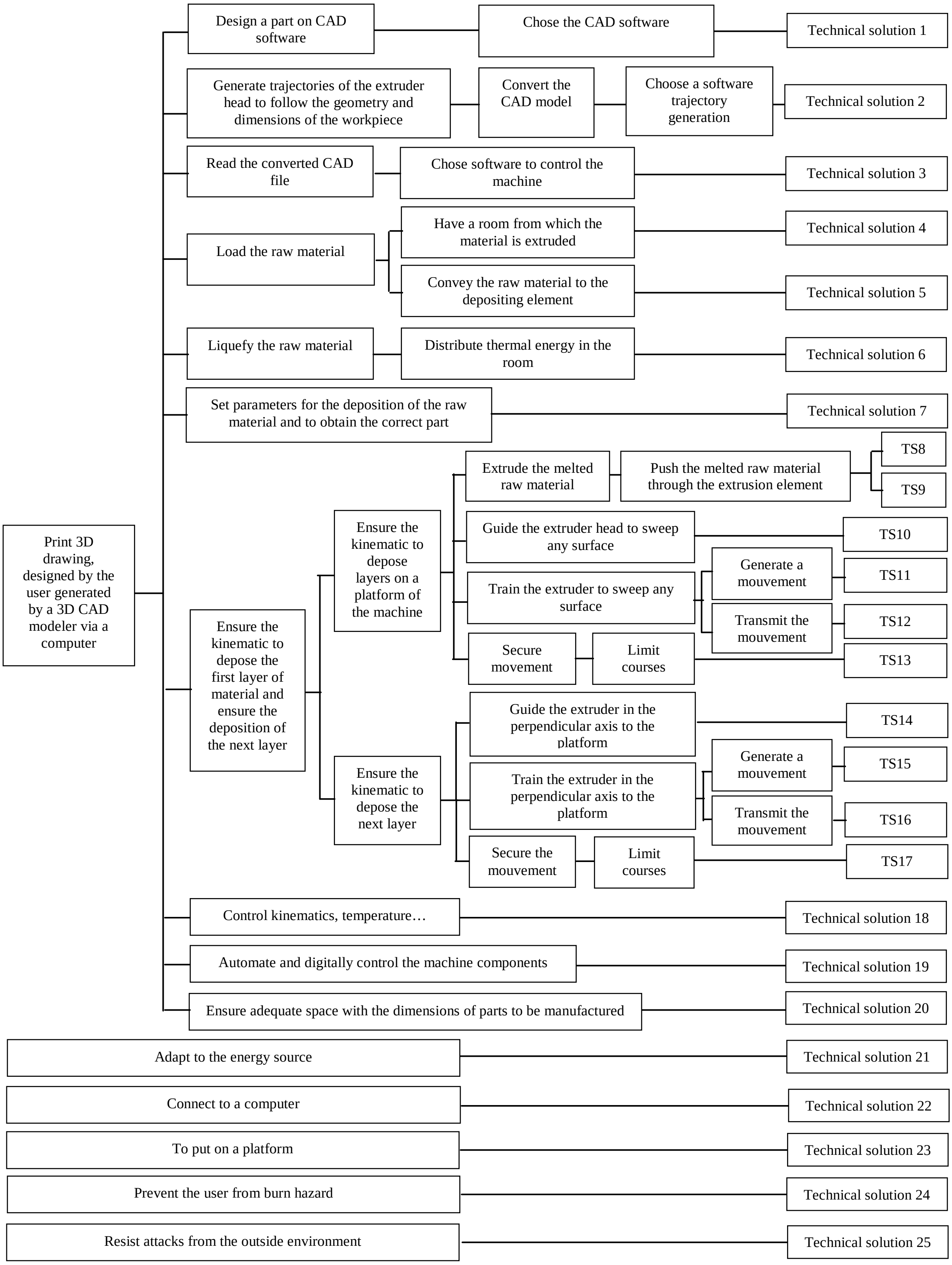

Fig. 3. FAST diagram applied to a 3D printer in the use phase of its lifecycle

To ensure the kinematic to depose layers on the platform of the machine, six sub-functions result. Pushing the melted raw material through the extrusion element (two sub-functions), guiding the extruder head to sweep any surface, training the extruder to sweep any surface by generating and transmitting the movement to the extruder (two sub-functions), and securing travels of elements that move. Note that these functions are not in the chronological order.

To push the melted raw material through the extruder, the raw material must be pushed and trained. These sub-functions are realized for 2PrintBeta , PRotos V2.0 and Portabee Go 3D Printer by a rack system which consists of a stepper motor and a drive screw. The stepper motor used for the three versions is a NEMA 17, however, 2PrintBeta , PRotos V2.0 and Portabee Go 3D Printer, use different drive screw which are, Hyena drive screw, MK7 drive gear, and M4 brass insert respectively.

To guide the extruder head to sweep any surface, the majority of 3D printers use an extruder and a platform moving relative to other in the XY plan, where the extruder moves in the X axis and the platform moves in the Y axis. for example, in the 2PrintBeta, guiding systems are realized by one 608zz bearing, three SC8VUU linear bearings and two 8mm smooth rods for the X axis, and two 608zz bearing, four SC8VUU linear bearings and two 8mm smooth rods, for the Y axis. For the PRotos V2.0, guiding systems are realized by one 624zz bearing, four LM8UU linear bearings and two 8mm smooth rods for both the X and Y axes. For the Portabee Go 3D printer, guiding systems are realized by one 624zz bearing, three LM6UU linear bearings, two 6mm smooth rods for the X axis, one 624zz bearing, four LM6UU linear bearings and two 6mm smooth rods, for the Y axis. It is clear that these systems use different sizes and types of linear bearing. The bigger is the linear bearing diameter and rod diameter, the more they can increase both the price and the weight of the printer. However, big rods diameters ensure good stability and robustness of the machine.

To guide the extruder head to sweep any surface, another type of 3D printers such as the Rostock uses an extruder that moves in X, Y and Z axes, while the platform where the part is build is immobile. However, its guiding systems are more complex to mount and use many components. Taking as an example, the X axis guiding system of the Rostock is realized by three 608z bearings, a cheapskate bearing assembly composed by ten bearing covers mounted to five 608z bearings, a two DOF linkage, one effector platform, one aluminum tower, and two Delta arms.

To train the extruder for 3D printers in which the extruder moves in the XY plan, the extruder must translate in the X axis, and the platform in the Y axis. The system used is a belt-pulley system where a stepper motor generates the rotating movement and a belt-pulley system transform the rotating movement to translating movement. The rotating movement for 2PrintBeta, PRotos V2.0, Portabee Go 3D printer for both X and Y axes, is generated by a stepper motor NEMA 17 each. While the movement transmission system differs. The 2PrintBeta uses a 2.5 belt guide (that is mounted in the 608z bearing), a small printed gear, and a belt, for both X and Y axes. The PRotos V2.0 uses two GT2 pulleys and a timing belt for both X and Y axes. While Portabee Go 3D printer uses one T2.5 pulley and a timing belt.

To secure travels of elements that move, some devises must be installed to prevent these elements from collisions with the machine. This function can be satisfied by at least three end-stops, one for each axis. 2PrintBeta and Protos V2.0 use LSMD1HT and Opto optical end-stops respectivly. While the Portabee Go 3D uses mechanical micro-switches.

B. Ensure the kinematic to depose the next layer

To ensure the kinematic to depose a next layer, the extruder must translate in the Z axis. Four sub-functions result. Guiding the extruder in the Z axis, training the extruder in the Z axis by generating a movement, transmitting it to the extruder, and securing travels of the extruder. However, in the literature, in the majority of 3D printers, the Z movement is applied to the platform, and not for extruder, besides the Rostock and Orion Delta versions. With this in mind, we have chosen to present some current 3D printers where the platform is moving.

To guide the platform in the Z axis, many solutions exist. 2PrintBeta uses two Bearing 608ZZ and four SC8VUU Linear bearings that slip in two 8mm smooth rods. PRotos V2.0 uses two LM8UU linear bearings that slip in two 8mm smooth rods. While the DiamondMind v2 uses two 608z bearings and two white printed bearing that slip in two aluminum tubing.

To train the platform in its perpendicular axis, the platform must translate in the Z axis. Another system rather than belt-pulley systems is used. This system is a screw-nut system where a stepper motor generates the rotating movement and a screw-nut system transform the rotating movement to translating movement. For both the Protos V2.0 and the 2PrintBeta, the Z axis training system uses two shaft coupling that serve to link two m8 threaded rods and two NEMA 17 stepper motors, and two M8 nuts. The X400 3D-Printer uses three M12 trapezoidal threaded rods attached to three 36 teeth pulleys, three M12 trapezoidal nuts, one NEMA17 stepper motor attached to a 16 teeth pulley that trains a timing belt to rotate the three pulleys and then, to rotate the threaded rods. The Orca 0.43 uses two ACME M8 nuts, two M8 threaded rods attached to GT2 36 teeth pulley, and a NEMA17 stepper motor attached a 16 teeth GT2 pulley that serves to train a timing belt to rotate the GT2 36 teeth pulleys, and then translate the assembled elements attached the two ACME M8 nuts.

To secure the travels of the platform, the most useful end-stops are optical end-stops and mechanical micro-switches.

By a judicious analysis to many 3D printers found in the literature, the different technical solutions to response the majority of sub-functions of the main function can be depicted in table 1 and table 2.

It can be remarked that the majority of these 3D printers' models share common technological solutions to satisfy service functions, with a difference of some mechanical and electrical components, their sizes, their number and their brands. The price, robustness, accuracy, weight, of these printers is different. It could be possible to give a weight of these characteristics each one, to sort an optimal printer in term of price and capabilities.

TABLE I. TECHNOLOGICAL SOLUTIONS USED IN 3D PRINTERS

3D Printer model	Undercarriage	Stepped motors	Printbed	Guiding system : X axis	Guiding system : Y axis	Guiding system : Z axis
2PrintBeta	Rods frame	5 x Motor Nema17	Heatbed PCB	3 x Linear bearings SC8VUU	4 x Linear bearing SC8UU	4 x Linear bearing SC8UU
PRotos V2.0	Bars frame	5 x Motor Nema17	heating mat 12V	4 x linear bearings LM8UU	4 x linear bearings LM8UU	2 x linear bearings LM8UU
X400 3D-Printer	Bars frame + Acrylic Case	5 x Motor Nema17	Heating pad	4 x linear bearings LM12UU	4 x linear bearings LM12UU	3 x linear bearings LM12UU
PRotos 3D-Drucker	Rods frame	5 x Motor Nema17	heating mat 12V	4 x linear bearings LM8UU	4 x linear bearings LM8UU	2 x linear bearings LM8UU
MendelMax 2.0	Bars frame	5 x Motor Nema17	MK2 Heat Bed	4 x linear bearings LM8UU	4 x linear bearings SC8VUU	4 x linear bearings LM8UU
DiamondMi-nd v2	Panels frame	5 x Motor Nema17	MDF Print Plate	2 x Printed linear bearing	2 x Printed linear bearing	2 x Printed linear bearing
Portabee Go 3D Printer	Rods frame	5 x Motor Nema17	Heatbed Romscraj	3 x linear bearings LM6UU	4 x linear bearings LM6UU	2 x linear bearings LM8UU
Printrbot Plus v2.1	Rods and panels frame	5 x Motor Nema17	MK2 Heat Bed	2 x bearing sleeve 8mm	2 x bearing sleeve 8mm	4 x LM12UU linear bearing
RepRap Pro Ormerod	Bars frame	4 x Motor Nema17	PCB heatbed	1 x LM12LUU linear bearing	3 x LM12UU linear bearing	2 x LM12UU linear bearing
RepRapPro Huxley	Rods frame	4 x Motor Nema14 + 1xNema 17	PCB heatbed	3 x LM6UU Linear bearings	3 x LM6UU Linear bearings	4 x 8mm IGUS bearings
RepRAP Pro Mendel	Rods frame	4 x Motor Nema17 + 1xNema 14	PCB heatbed	3 x LM8UU Linear bearings	3 x LM8UU Linear bearings	4 x 8mm IGUS bearings
Rostock MAX	Aluminum tower frame	4 x Motor Nema17	Melamine heated bed	Cheapskate bearing + DOF linkage + effector platform	Cheapskate bearing + DOF linkage +2x delta arms	Cheapskate bearing + DOF linkage+2x delta arms
Prusa i3	Rods and wires frame	5 x Motor Nema17	HBP heatbed	3 x linear bearings LM8UU	3 x linear bearings LM8UU	4 x linear bearings LM8UU
3drag	Bars frame	4 x Motor Nema17	Heated plate	4 x linear bearings LM8UU	4 x linear bearings LM8UU	5x linear bearings LM8UU
FoldaRap	Bars frame	3 x Motor Nema17 + 1xNema 14	TEC1 12708 Heated-Bed	3 x RJMP-01-06	3 x LM6UU	2 x bars +2 x printed parts
Orca 0.43	Sheet frame	4 x Motor Nema17	Aluminum plate +4× ARCOL HS15 resistors	3 x linear bearing LM8UU	3 x linear bearing LM8UU	4 x linear bearing LM8UU
Prusa Mendel	Threaded rods frame	5 x Motor Nema17	V2 Heatbead	4 x printed bushings 8mm	4 x printed bushings 8mm	4 x printed bushings 8mm
Adrians Pursa	Threaded rods frame	5 x Motor Nema17	9 x 12 ohm resistors + Aluminum plate	4 x printed bushings 8mm	4 x printed bushings 8mm	4 x printed bushings 8mm

However, all these printers share the same drawbacks. Concerning the time to manufacture products, professional machines take hours, even days, to create an object of moderate size. A consumer 3D printer can be even slower. Fastest impressions are small objects, which will still one to two hours to be produced. As far as we are concerned, print failures is also a common problem for all these 3D printers presented above, A piece that collapses, a supply problem, a discoloration due to heat, or simply a power outage during a long printing can happen, and happen frequently. Concerning surface roughness, Items purchased in the shops are usually smooth and shiny, unlike 3D printed objects where we can distinguish the layering. There are of course ways to post-treatment for the finish product, but the product price increases. Another problem is that these 3D printers cited above, can produce plastic objects, some in several different plastics. There are machines that can print in other materials such as metal, ceramic, glass or even food, but it will push the demander to invest in more expensive machines, or build a personal 3D printer that prints using other materials.

It is clear that these problems are common for the majority of 3D printers, in addition to that, each 3D printer can have its particular problems. Due to the fact that the aim of our study is to develop a new 3D printer based on an Orca 0.43, and after assembling the machine, we have tested the machine and printed many objects. According to our experience, we have confronted some problems and which can be resumed us following:

- Very difficult assembly, calibration, and leveling
- Linear bearings lose their ball during the assembly phase which increases friction
- The big printed gear of the extruder slips due to loosening which can influence the raw material flow and then, the quality of the product
- The 100K NTC thermistor breaks easily
- The temperature of the bed does not reach the required temperature causing the detachment of the workpiece during impression.

TABLE II. TECHNOLOGICAL SOLUTIONS USED IN 3D PRINTERS (SUITE)

3D Printer model	Motion transmission : X axis	Motion transmission : Y axis	Motion transmission : Zaxis	Extruder	Motherboard	Software/ firmware	End-stops
2PrintBeta	2.5 Belt guide + belt + printed gear	2.5 Belt guide + belt + printer gear	2x Threaded rod M8 + 2x shaft coupling	J-Head MK-IV	RAMPS 1.4 + Arduino MEGA 2560	Arduino / FTDI/sprinter Printrun/Slic3r	optical end-stops LSMD1HT
PRotos V2.0	2 x Pulley T2.5 + timing belt	2 x Pulley T2.5 + timing belt	2x Threaded rod M8 + 2x shaft coupling	DD Extruder single	RAMPS 1.4 + Arduino MEGA 2560	Arduino / FTDI /Protos :Repetier/Host/ Slic3r	3 x Opto End-stops
X400 3D-Printer	2 x Pulley 16 teeth + belt	2 x Pulley 16 teeth + belt	3x Pulley 36 teeth + 3x threaded rods + belt +1x Pulley 16 teeth	DD Extruder single	RAMPS 1.4 + Arduino MEGA 2560	Arduino / FTDI /Protos :Repetier/Host/ Slic3r	3 x Opto End-stops
PRotos 3D-Drucker	1x Pulley M3x3 + belt + Pulley T5	1x Pulley M3x3 + belt + Pulley T5	2x Threaded rod M8 + 2x shaft coupling	DD Extruder single	RAMPS 1.4 + Arduino MEGA 2560	Arduino / FTDI /Protos :Repetier/Host/ Slic3r	3 x Opto End-stops
MendelMax 2.0	T5 Timing belt + 1 x Pulley T2.5	T5 Timing belt +1x Pulley T2.5	2x Threaded rod M8 + 2x shaft coupling	Assembled extruder	RAMPS 1.4	Arduino / FTDI/Firmware/Marlin/Printrun /Slic3r	3x micro-switches
DiamondMi-nd v2	1 x Pulley GT2 + belt	1 x Pulley GT2 + belt	2x Threaded rod M8 + 2xshaft coupling	Assembled extruder	RAMPS 1.4	Arduino / FTDI/ DMV2/ Repetier/ Slic3r	3x micro-switches
Portabee Go 3D Printer	1 x Pulley T2.5 + belt	1 x Pulley T2.5 + belt	2x Threaded rod M6 + 2x printed shaft coupling	Romscraj extruder	Gen 6 Deluxe	VCP /D2XX/ Pronterfac/ Slic3r	3x micro-switches
Printrbot Plus v2.1	1 x Pulley GT2 + GT2 belt	1 x Pulley GT2 + GT2 belt	2 x Acme rod +2 x P50 pieces	Assembled extruder	Printrboard rev D	Serial install/ Reptier/Slic3r	3x micro-switches
RepRap Pro Ormerod	1 x MXL pulley +printed gear +blet	1 x MXL pulley +blet	M5 threaded rod + drive/driven gears	Assembled extruder	Duet board	Arduino environment/ RepRap/ Pronterface/ Slic3r	3x micro-switches
RepRapPro Huxley	MXL printed pulley + belt	MXL printed pulley + belt	M5 threaded rod + 4 x Printed clamp	Assembled extruder	Melzi controller board	CDM20824 pyglet-1.1.4.msi /Marlin Pronterface/ Slic3r	3x micro-switches
RepRAP Pro Mendel	printed pulley + belt	printed pulley + belt	M8 threaded rod + 4 x Printed clamp	Assembled extruder	Melzi controller board	CDM20824 pyglet-1.1.4.msi /Marlin Pronterface/ Slic3r	3x micro-switches
Rostock MAX	1 x pulley +6 x Idler bearing components + belt	1 x pulley +6 x Idler bearing components + belt	1 x pulley +6 x Idler bearing components + belt	EZStruder	RAMBo v1.2	RAMBo/ Arduino/ReptierMax Reptier/ Slicer	3x micro-switches
Prusa i3	1 x Pulley GT2 + belt	1 x Pulley GT2 + belt	2 x coupler tubes +2 x M5 threaded z-rod	Assembled extruder	RAMPS + ATMEGA2560	Arduino/ FTDI. Marlin/Pronterface /Slic3r	3 x mesh end stops v 1.0
3drag	1 x Pulley 16 teeth +belt	1 x Pulley 16 teeth +belt	1 x M5 threaded z-rod+1 x aluminum joint	3drag extruder	Sanguinololu + ATmega2560	Arduinot /FTDI/ Marlin/ Reptier/ Slic3r	3x micro-switches
FoldaRap	1 x GT2 Pulley +belt	1 x GT2 Pulley +belt	2 x vinyl coupling +2 x M5 threaded z-rod	Emaker huxley hotend	Minitronicsv1 Or Azteeg X1	Arduino/FTDI Marlin/Software/ Pronterface /Slic3r	3x micro-switches
Orca 0.43	1 x GT2 Pulley +belt	1 x GT2 Pulley +belt	2 x ACME M8 nut+2 x M8 threaded z-rod + 2x GT2 Pulley 36 Tooth+belt+ GT pulley 16 teeth	Extruder V10/v10B	GEN6 Deluxe	Arduino/FTDI/ Marlin/ Pronterface / Slic3r	3x optical endstop H21LOB
Prusa Mendel	1 x printed gear +belt	1 x printed gear +belt	2x printed coupling +2 x M8 threaded z-rod	Assembled extruder	RAMPS 1.4 + arduino board	Arduino/python Marlin/sprinter Pronterface/print run skeinforge	3x micro-switches
Adrians Pursa	1 x printed gear +belt	1 x printed gear +belt	2x printed coupling +2 x M8 threaded z-rod	Universal Mini Extruder	Sanguinololu	Arduino/ Gen7 Arduino IDE/ sprinter/marlin/teacup Pronterface/printrun/ skeinforge	3x micro-switches

V. CONCLUSION

In this paper, we have followed a systematic approach by applying functional analysis. The purpose of this systems engineering process activity is to transform the functional performance, interface and other requirements that were identified through requirements analysis into a coherent description of system functions that can be used to guide the Design Synthesis activity that follow. By applying this approach, we started first by determining the need of the 3D printer, and after, we have selected all exterior elements that can affect the machine. Relations between these features with the machine result in service functions. These service functions are developed by the Function Analysis System Technique (FAST), to draw the technical functions to meet these functions. In the end, we have presented a survey and analysis of some of different technical solutions used for various 3D printers, and we have mentioned some problems. This structured methodical approach will help us later to develop a new 3D printer, which will be the goal of our next paper.

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