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Recent trends and technologies in rapid prototyping and its inclination towards industry 4.0

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Abstract

Prototyping technology is becoming vital in the business as a means of cutting costs and manufacturing time. At present, reverse engineering and rapid prototyping are important technologies that enhance prototype development. The traditional approaches require various intricate processes, such as selective heat sintering (SHS), digital-light-processing printer (DLP), remote distributed rapid prototyping model (RDRP), Stereo lithography (STL) models, and reconstructing computer-aided design (CAD) models from scanned point data and these approaches has limitations in terms of time-consuming and expert knowledge required for automation. This study aims to explore the significance of Industry 4.0 and its impact on rapid prototyping. The study also addresses rapid prototyping in computer network architecture; digital-light-processing printers (DLP) in rapid prototyping, and software-defined network (SDN) networks in the con-text of rapid prototyping. Along with this powder bed fusion (PBF) method and electron beam melting (EBM) are included in the manuscript. Based on our exploration, the study suggested vital recommendations for the advancement in rapid prototyping using Industry 4.0

Keywords: Sustainable, Innovation, Industry 4.0, DLP; STL; Rapid prototyping; CAD; IoT

1. Introduction

The Sustainable Development Goals (SDGs) are the cornerstone of the 2030 Agenda for Sustainable Development and the framework for all national, regional, and global development activities throughout the subsequent fifteen years. The United Nations Industrial Development Organization (UNIDO) contributes to the SDGs by doing the following initiatives. Encourages the development of innovative, resource-efficient, and competitive smart industries and industrial clusters in urban industrial zones that connect regional businesses to global markets and supply networks. The effectiveness of product realization processes, systems, and equipment is evaluated in terms of societal, economic, functional, and environmental factors [1]. To provide a fair and thorough evaluation of manufacturing's performance in terms of sustainability at the levels of products, processes, and systems, both a framework and metrics have been established [2]. The main production of materials, tools, and gadgets has been discovered to cause a significant amount of environmental burden, particularly for manufacturing operations [3]. Rapid prototyping is now widely employed in the processes involved in creating new products. For design evaluation, RP creates physical representations straight from 3D CAD models [4, 5]. In RP, physical models are created by layering new materials using additive manufacturing techniques such as selective laser sintering (SLS), stereolithography (SLA), and laminated object manufacture (LOM). Compared to other traditional manufacturing processes, these procedures require a lot of energy. Therefore, traditional subtractive manufacturing techniques can also be considered to increase the sustainability of rapid prototyping.

One of the interesting alternatives in this regard is rapid prototyping made from woody materials [6, 7]. High-performance n-type BiTeSe on a large scale using SHS-based 3D printing completes development from ingredients to modules using rapid prototyping IoT and using the SLS technique [8]. The number of physical objects connected to the internet during the past ten years has grown dramatically. This phenomenon is known as the "Internet of Things" (IoT). Cloud technology has so far been essential to the large-scale implementation of IoT services. The IoT services rely on the cloud to provide on-demand storage, computing, and network infrastructure. Recent trends predict that over 1 trillion IoT devices will be incorporated into smart systems by 2025, along with a 50% increase in latency-sensitive services [9]. At present, technology can simply print the 3D object's surface. The creation of filling paths inside contours will be the focus of upcoming work to print solid objects. Future work will also involve creating an algorithm that will allow the production of different contours in each sliced layer. It has been identified from previous studies that the significance of Industry 4.0 and rapid prototyping in product development. With the motivation from the above facts, this study aims to investigate and explore the significance of Industry 4.0 and its impact on rapid prototyping. The main contribution of the study is as follows:

- To explore the significance of Industry 4.0 and its impact on rapid prototyping;
- The study also addresses rapid prototyping in computer network architecture; digital light processing printers (DLP) in rapid prototyping, and software-defined network (SDN) networks in the context of rapid prototyping. Along with this powder bed fusion (PBF) method and electron beam melting (EBM) are included in the manuscript;
- Based on our exploration, the study suggested vital recommendations for the advancement in rapid prototyping using Industry 4.0.

This paper is organized in the manner that section 2 gives a concise overview of rapid prototyping, while section 3 briefly discusses the rapid manufacturing method information, talking about DLP; SDN, and PBN for rapid prototyping. The discussion and recommendations are presented in section 4.

1.1. Overview of rapid prototyping

Technology for rapid prototyping has received a lot of interest. Rapid prototyping's objective is to shorten the manufacturing process and make complicated geometric designs and small-batch productions more affordable [10]. A computer-aided design (CAD) model allows people to produce their parts whenever and wherever they want. With today's technology, it is possible to transmit the facet model from the CAD model as an STL file for printing. Fused Deposition Modeling is one of the most well-liked 3D printing processes (FDM). The material will be formed into wires, melted within a nozzle, and then deposited in the form of a layer behind it to create the object. In a computer-aided design (CAD) context, reverse engineering (RE) is the process of replicating or building an exact size physical object or surface [11]. A CAD model is created using points that are on or near the target item or surface. The method has been used in the automotive, aerospace, healthcare, and custom product industries [12], where it necessitates several free surface reconstructions. In contrast, the traditional method necessitates arduous labor and expert understanding. Users must be conversant with multiple modeling software packages. Such proficiency demands years of expertise using the software [13, 14]. In addition, both RE and RP techniques forfeit precision, and glitch originating from the CAD model rises to issue, known as the "stair-step" error, during the printing of a sliced object [15,16]. The research proposed an automatic prototyping system that fully integrates RE and the rapid prototyping process to overcome the disadvantages of the conventional techniques stated previously. The evolution of cloud servers has empowered the implementation of cloud-based services in manufacturing to adopt digital services. The data is captured via a cloud server utilizing 3D sensors such as X-rays, 3D scanners magnetic, and mechanically digitizing devices. The acquired information normally encompasses the object's position in the 3D coordinate system [17, 18]. Rebuilding or duplicating a physical thing traditionally involves multiple processes. First, a 3D scanner collects the information from the cloud to final solid CAD model must be produced using the cloud data as input. The CAD model must then be transformed into a facet model, such as a Stereolithography (STL), and then split to create the contours on each slice, hence generating the printing routes. Figure 1 shows the operational sequence of data initiation to final manufacturing. In the suggested entity, the cloud input from a 3D scanner is received as instruction, and then the point cloud is directly sculpted using the given technique to get the sliced contour. The suggested system does not generate CAD models or STL models. Since the FDM method has been successfully marketed for use in education, individual design, and prototyping, it is now widely available on the market [19, 20]. In our system, an FDM printer will be linked to pursue the printing route and produce the desired object. A user-friendly juncture is built for the systems, which is implemented using MATLAB. Recently, there has been an increase in interest in AM technology [21, 22] commonly known as 3D-P technology. Different materials, material phases, working environments, and fabricating technologies have led to the development of numerous 3D printing subfields [23, 24].

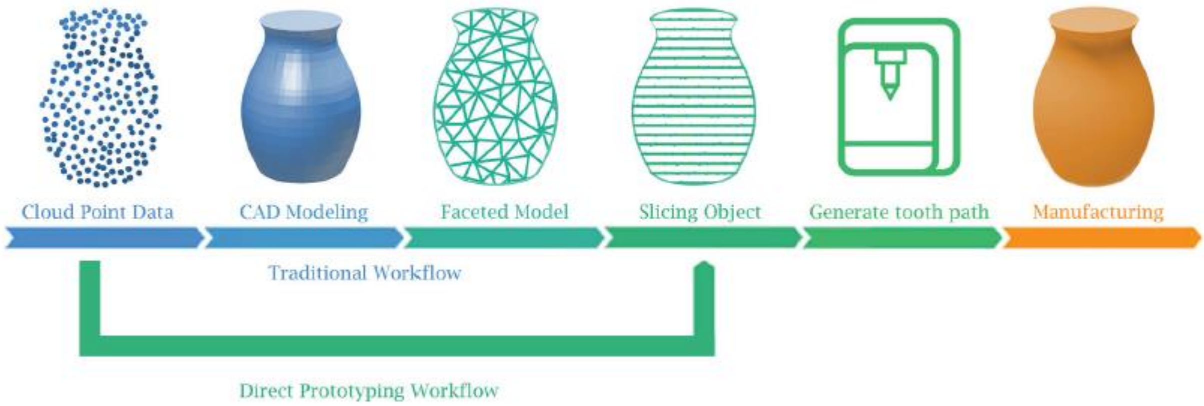

Figure 1. A comparison of conventional prototyping and proposed direct prototyping techniques

2. Research method

2.1. Investigation of the prototyping-manufacturing method

The purpose of the prototype is to decrease production time and material costs, as well as to enhance printing quality [25]. In the slicing methods [26, 27], the support material is printed based on the main document and then cast off [28, 29].

2.2. Rapid prototyping in computer network architecture

The rapid prototyping process consists of many basic aspects that may vary somewhat depending on the technology employed [30] and the outline of the RP process is presented in Fig. 2. The first stage of fast prototyping is always associated with conceptual work and the production of an initial 3D or 2D model.

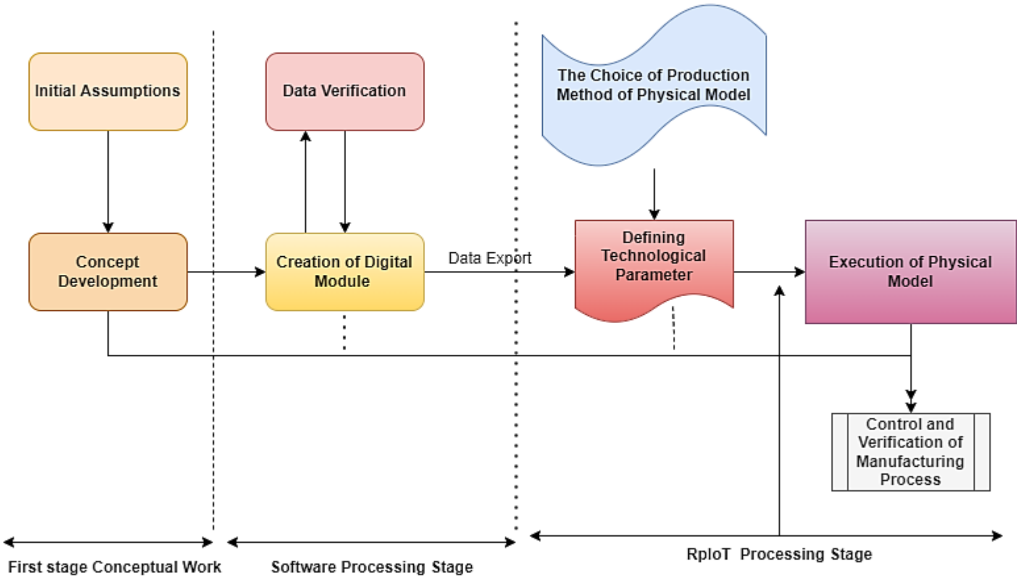

Figure 2. Schematic of the rapid prototyping process

In the subsequent processes, a digital model is often created using general-purpose and solution-specific CAD software. At this point, the data about the modeled object can be validated and any necessary corrections are made following the basic assumptions established during concept creation. It should be noted that any adjustments made at this stage save time and potential costs associated with future corrections. There are numerous methods of physical object production in the RP process, such as SLA, photopolymer layering and curing (PolyJet), SLS of metallic powders, fused deposition modeling (FDM), and three-dimensional printing (3DP) [31, 32]. The modern production systems, particularly those based on the architecture of Industry 4.0, are distributed systems. This category of systems relies heavily on the exchange of data between the nodes. Intriguingly, a node in the case of fast prototyping systems correlates to the individual stage in Fig. 2. It should be noted that, as we stand on the cusp of a new industrial revolution, it is necessary to ensure that new solutions are compatible with industry 4.0 [33,34].

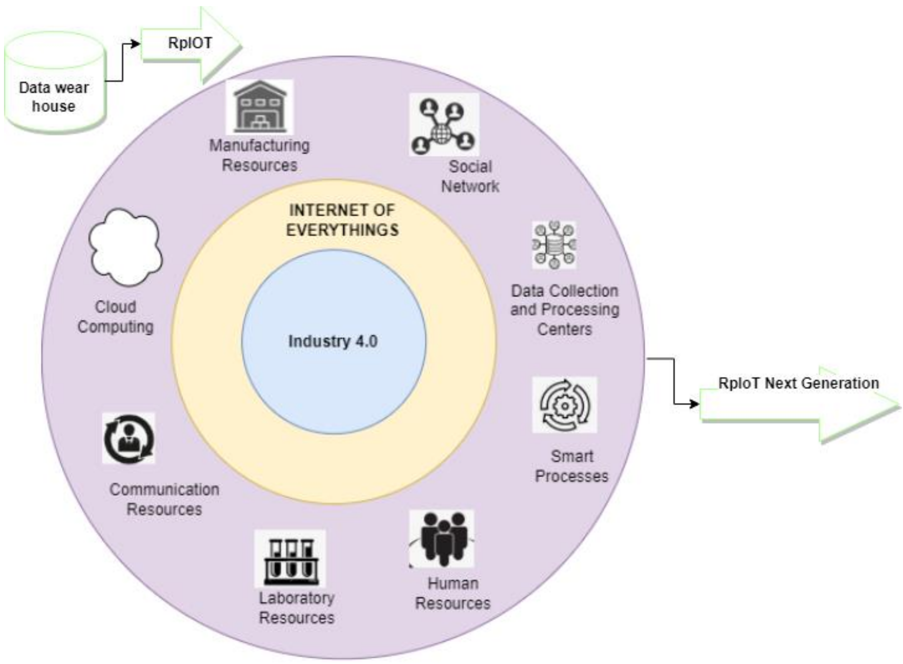

Figure 3. Integrated industry 4.0

Fig. 3 is a diagram exhibiting a selection of Industry 4.0 elements that should be interconnected with one another. Figure 3 is an example of a conventional network infrastructure that permits the integration of distributed parts involved in the RP process [35, 36]. With the use of broadband computer networks, it is possible to place remote components while keeping transmission quality parameters. However, the traditional approach to computer network administration is highly reactive, as evidenced by the following. Figure 4. shows the network architecture that supports fast and accurate prototyping.

2.3. Use of digital-light-processing printer (DLP) in RP

Digital Light Processing (DLP) printer uses a digital projector to selectively cure a whole layer of resin using a digital projector based on a mask image [37]. The material tower is compactly designed to enable the storage and retrieval of various printing materials. Spray mechanisms are utilized to actively remove surplus resin between material changes [38]. The system has a cleaning efficacy of over 90 percents in 15 seconds with a 72-inch build area, whereas the prior work achieved just 50 percent cleaning effectiveness in two minutes with a 6-inch build area. Using a spraying mechanism makes the entire system sustainable and scalable. Additive manufacturing (AM) is not only utilized for rapid prototyping, but also rapid manufacturing (RM) [39], and the cost of end-use parts created with AM has become a significant aspect in determining the viability of business cases for this manufacturing technology [40].

2.4. The concept of SDN network in the context of RP

The use of a Software defined network (SDN) is addressed in detail in this study [41, 42]. It differs from the conventional paradigm in terms of how the communication environment is managed generally. A simplified communication system that links many L1 to Ln locations is shown in model form in Figure 4. Network devices (ND) connect components used in the RP infrastructure (RPDI) method to form the communication system. The purpose of a computer network is to promote inter-computer interaction [43, 44]. To develop safe communication channels on demand, the communication environment must adapt swiftly. Each network device functions with its autonomous control system and data transfer at each location in the traditional topology [45].

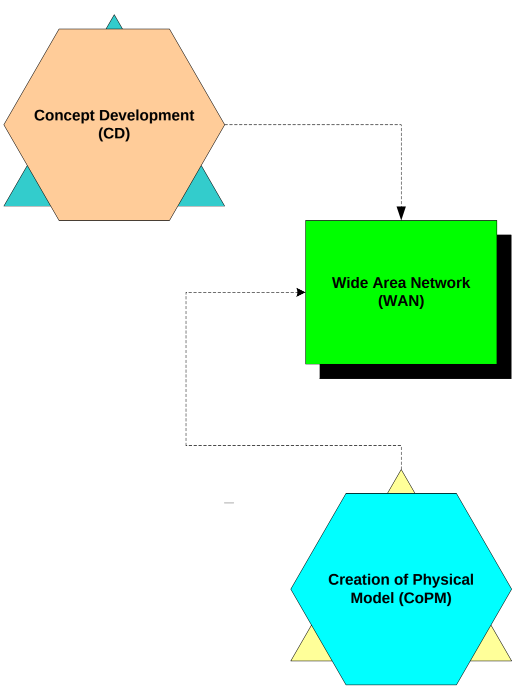

Figure 4. Block diagram of the network architecture that supports fast prototyping

In the ideal scenario, a specialized network management system (NMS) program that gathers data from devices, and reactively manages them in the case of a homogenous structure, manages the entire environment from a single location [46]. It should be emphasized that there are typically dozens of incompatible data gathering and control protocols in the network in the classical example. The Control plane layer in the SDN paradigm is moved from the device to the controller, where it is implemented as software.

Considering the above-described issues, the authors proposed a new hierarchical model called the remote distributed rapid prototyping model (RDRP) (Figure 5). This model allows referring to all mechanisms, processes, and technologies accompanying rapid prototyping in the environment of distributed IT networks and in the computing cloud. Components of a distributed system can be individual devices, computers but also the entire production lines. As a rule, entities are manufactured by different manufacturers and subcontractors [47]. The use of the model allows us to clearly define which elements must be implemented in each entity to be able to communicate with other entities in RDRP. In contrast, data flow at individual nodes is carried out from top-down and bottom-up, with a restriction on the layer being processed on a given node, of course [48]. As a result, the rapid prototyping layer approach from individual entities creates one distributed prototyping system that is made available to remote users, thus creating remote distributed rapid prototyping (RDRP). This approach is beneficial for cost, security, and implementation time [49].

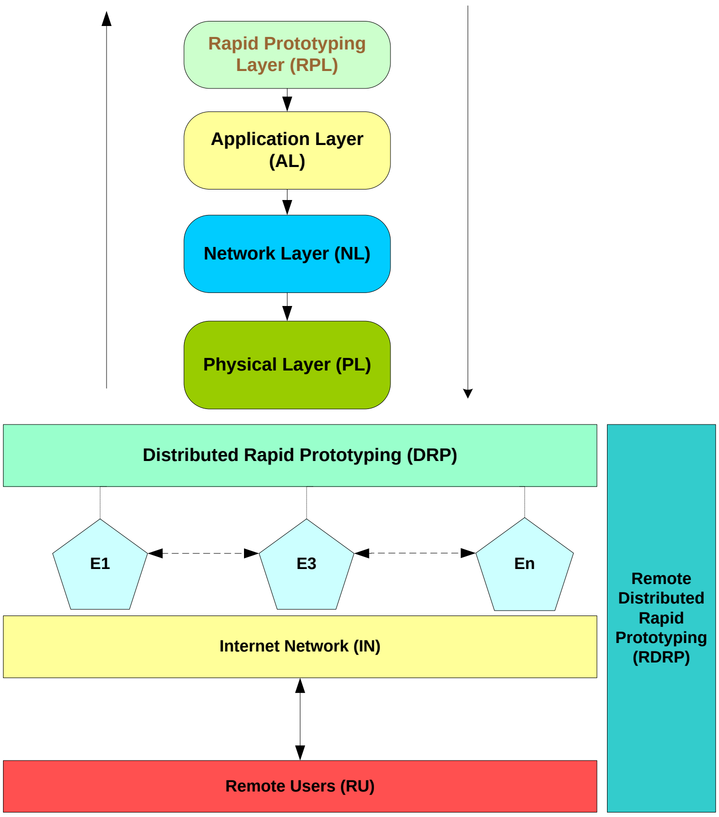

Figure 5. Different layers of rapid prototyping

2.5 Powder bed fusion (PBF) method

The PBF method is an innovative manufacturing mechanization used to manufacture actual items from the needed 3D solid CAD model information using the notion of layer-by-layer addition [50, 51]. Powder particles are irradiated, fused, and melted using either laser or EB as the heat energy source. Various types of lasers are the most prevalent heat sources employed in PBF. The varieties of PBF procedures are direct metal laser sintering (DMLS); SHS; SLS; and EBM.

a) Process of direct metal laser sintering (DMLS)
DMLS is identical to the SLM technique; Figure 6 depicts the DMLS procedure [52, 53, 54]. Direct metal laser sintering is utilized to produce short-run components, functional prototypes, and practically graded materials (PGM). Aerospace components can be manufactured with fewer and cheaper raw materials.

b) Process of selective heat sintering (SHS)

A heated head causes plastic powder particles to fuse. Under the sliced STL model, the hot head contacts the powder and moves. Manufacturing structural components and conceptual prototypes is done using this technique. Blue printer, a desktop 3D printer, employs SHS technology [55]. It has a built-in chamber that measures 200 mm by 160 mm by 140 mm, prints at a rate of 0.078 to 0.118 inches per hour and uses a 0.0039-inch layer thickness.

c) Selective laser sintering (SLS)
Here is an illustration of the SLS approach concerning Fig. 6. When the powder supply piston rises, a roller mechanism can disperse powder on the platform that has been built. To create the initial sintered layer, the LB can scan the powders completely and fuse or sinter the powder particles using 3D CAD data. The needed thickness of the part of the construction bed can be moved down, and a second layer of powder is distributed over the first sintered layer. The second layer is then fused onto the first layer after the laser beam scans again with precision. The procedure can be repeated until every physical component has been built. The procedure can be repeated until every physical component has been built. The component is removed from the RP machine and cleaned, if necessary [56, 57, 58]. Figure 6. defines the actual process involved in the SLC Rapid prototyping process. Starting from raw material to finished products with the use of process.

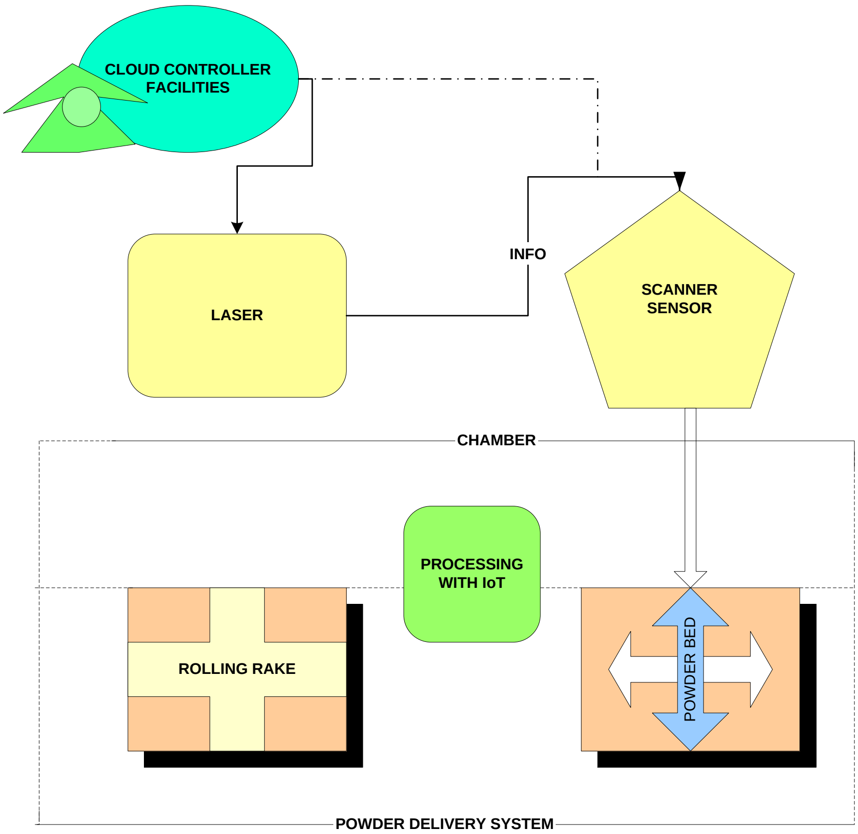

Figure 6. Process diagram of SLC

d) EBM is a powder blinding technique and uses, the heat energy source for melting powder metal [59, 60, 61] shown in Fig 7. In EBM, 2- magnetic fields, the focusing coil, and the deflecting coil, can be used to control the high-speed emission of electrons from a heated tungsten fiber. A tiny electron beam with a diameter of 0.1 mm is produced by the focusing coil, and a refracting coil directs the focused beam at certain locations for scanning an alloy powder layer. The way that EBM functions is as follows. In the constructed chamber, high vacuity and high temperature can be preserved. Powder hoppers spread an alloy powder coating over the constructed chamber. By using a focused electron beam, the powder particles melt in a limited area within the layer. To define a 2D and 3D slice of the object into the layer, the electron beam is used.

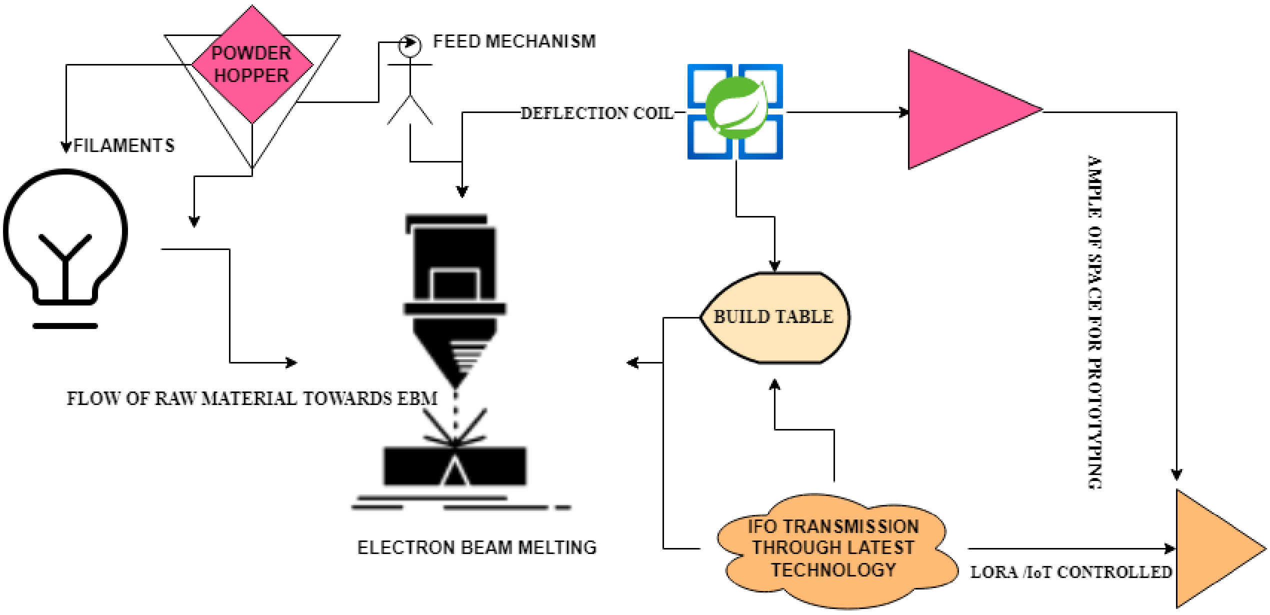

Figure 7. Electron beam melting (EBM)

2.6 Rapid prototyping tools in the electronic and electric domain

The idea behind virtual prototyping is to forego building and testing physical prototypes to use software to assess the functioning of potential power electronic systems, component designs, and subsystems. Therefore, virtual prototyping can cut down the time and expense associated with assessing the effectiveness of potential designs. Several design iterations are employed in the iterative process of virtual design optimization to develop the original design concept until it fulfills a set of design constraints and achieves a desired performance objective. The lumped element, compact or similar circuit model is a method frequently used for multi-domain physical simulation in power electronics. To explain the important system features using a manageable number of ordinary differential equations, this method discards spatial information. Quasi-static electromagnetic parasitic [62] and thermal [63] effects frequently reduced to these compact models. The challenges with this strategy for virtual design optimization are the method needed for the automatic creation of equivalent circuits from a 3D model of the design, and the models must then be uploaded from the modeling program and built in the circuit simulator autonomously. Automation of this primarily manual process appears to be the overall trend in power electronics virtual prototyping. The difficulty of model creation has been addressed in previous studies [64, 65], as well as the integration of these models into circuit simulators [66]. The optimization of multi-chip power electronic modules based on their dynamic thermal performance was demonstrated using a novel method that employs mathematical optimization techniques in Rapid prototyping [67]. A 3D inductance extraction tool with multi-pole acceleration technique [68, 69], extraction of heat equivalent circuits from 3D-field simulations, and their immediate insertion into the circuit simulator are a well-known solution to this issue [70].

3. Recommendation and findings

Rapid prototyping plays a significant role in which it describes the lifecycle of product development. The integration of real-time data enables the development of real products with flexibility and minimum cost. Based on this, this study explored the significance of rapid prototyping concerning Industry 4.0, and as a conclusion this study discusses the recommendations for future work:

- IoT has enormous potential to improve teamwork across a variety of application fields. Internet connectivity for common place items and settings encourages all-encompassing information access and system integration. Rapid prototyping IoT facilitates the creation of collaborative applications by facilitating the specification of high-level data type primitives and permitting interactions dispersed across numerous smart devices. An Antenna for Mmwave 5G communications made by Direct metal laser sintering, is suggested to be used for indoor 5G New Radio applications.

- Rapid prototyping is frequently a relatively affordable option when building prototypes, especially when the time and expense of using more conventional methods or waiting for initial tooled pieces are considered. In the essay Objectify technologies (a developer of rapid prototype solutions) discusses the benefits of fast prototyping, examines recent developments, and audits various prototyping processes and considerations that should be made.
- Innovations need to accelerate their periods and build for the following cycle in a world where people are constantly searching faster for the appropriate moment to advertise. By introducing new products more quickly, fast prototyping gives businesses the ability to remain competitive. In addition, rapid prototyping in the automotive, oil and gas, white goods, aerospace, and space industries offers a significant incentive by allowing for the creation of a prototype before the main component is constructed, saving millions, if not billions of dollars, and allowing to produce the final component for functional use in the shortest amount of time.
- As a low-cost option for expert PCB design and as a tool for quick prototyping for R&D, the Proteus Design Suite is extensively used across many industry sectors. Before placing the first physical PCB order, system testing is possible with virtual prototyping. For electronic prototyping, Arduino is a free and open-source platform. A designer can attach an Arduino board (like the Uno) to a breadboard, plug in a few components, including inputs, sensors, lights, and displays, and then write code to regulate how they work together.
- A quick prototype tool called In Vision unifies all your design tools in a single workspace. You may create completely interactive mock-ups with InVision by uploading any static design file you have. Incorporating hotspots, preserving transitions, and adding hover states are just a few of the capabilities that enable you to see how your app will function after it goes live. For developers trying to expedite and simplify the design process, Marvel is a great quick prototype tool. In addition to being a robust rapid prototype tool, Framer is also a full-featured design platform. You may quickly export frames and shapes as bitmaps or vectors using the rich vector editing toolbox provided by Framer.
- The rapid development of prototypes is gradually incorporating more AI. One of the key elements of excellent product prototyping is making data-driven decisions and conducting tests seamlessly.

4. Conclusion

Environmental degradation is one of the constraints of the industrial revolution. The implementation of the sustainable approach empowers them to overcome the different constraints. In this study, we have discussed rapid prototyping and its inclination towards Industry 4.0. A thorough analysis has been presented in the article to discuss the different parameters that are significant in rapid prototyping for product development. This study addressed the various methods that are helpful in the field of rapid prototype development with an emphasis on digitalization. Based upon the above analysis, the study discussed findings and different recommendations for future enhancement in rapid prototyping with Industry 4.0. InVision is a prototyping tool that unifies all your design tools in a single workspace and Marvel is a great quick prototype tool. In the future, there is a need to adopt different Industry 4.0 technologies in rapid prototyping for the future environment such as sustainability.

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Conflict of interest

We have taken the references of other publishers and drafted this article. We have not submitted the manuscript, figures, and tables presented in this article to any other journal for consideration. No conflict of interest.

Author contribution

The contribution to the paper is as follows: Yashwant Singh Bisht, Rajesh Singh, Anita Gehlot: introduction and overview part**;** Shaik Vaseem Akram, Amit Kumar Thakur: methods; and Neeraj Priyadarshi, Bhekisipho Twala: results and finding conclusion.

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