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A Survey and Feasibility Research Study on Computer Aided Process Planning (CAPP)

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Abstract: ***Computer Aided Process Planning (CAPP) is the use of computer system to help and guide process planners in planning and executing different functions. It has emerged as one of the crucial links between integration of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). In this paper, an attempt is made to provide a complete survey of CAPP based on different methodology namely, features and solid model, neural networks, optimization, fuzzy logic, knowledge based, web based, hybrid manufacturing, artificial intelligence, virtual, (STEP)-compliant method. The aim of this paper is to provide an update, in and after year 2000, in field of CAPP systems using survey and representing graphically for easy understanding***

Keywords: CAPP, CAD, CAM, Methodology, Variant, Generative.

I. MOTIVATION

The significance of CAPP in a manufacturing facility cannot be undervalued. One of the logics for this support is that it provides a critical link between design and manufacturing and at the same time it reduces the time and cost and improves the quality as well. So, a comprehensive survey is done to present its role.

II. INTRODUCTION

In the past two decades, more than hundred different CAPP systems with variant, generative and hybrid approaches are developed by human beings to assist them in planning. It has emerged as one of the important links between integration of CAD and CAM. It is one of the principal components in computer integrated manufacturing. A lot of research has been carried out in this area, one of the main reasons being reduction in throughout time and improvement in quality. CAPP is the use of computer to help process planner in planning functions. There are broadly two approaches in CAPP: Variant and Generative.

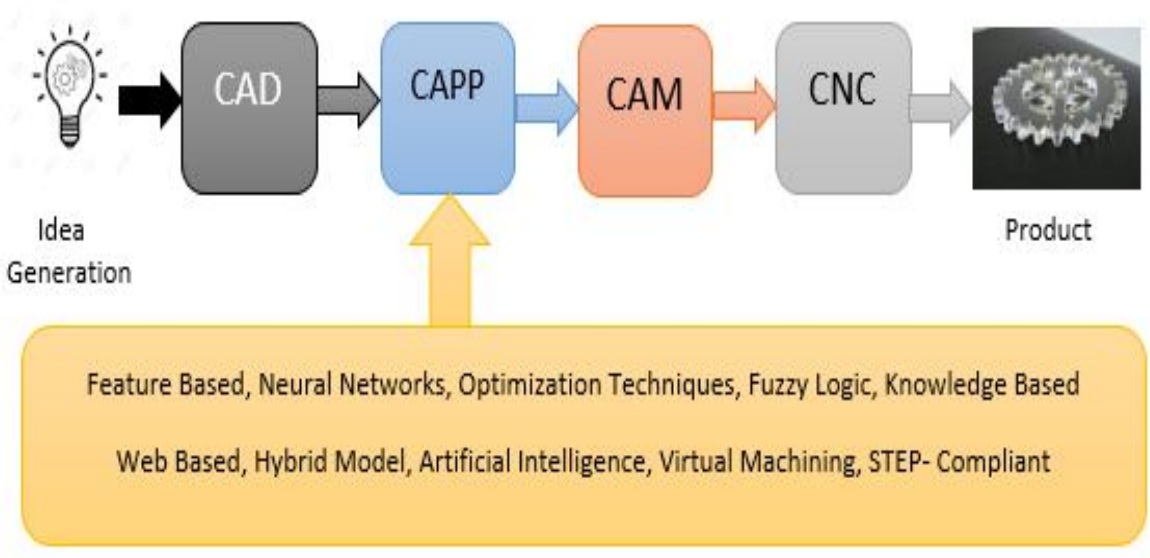

Fig.1 CAPP in manufacturing cycle.

A. Variant

Also called as retrieval method. In this approach, process plan for a brand-new part is created by recollecting, recognizing and retrieving an existing plan for an analogous part and making necessary modifications in the existing part. It basically selects generic process plan from established master process plan, developed for each part family and then modify it to suit as per the requirement of new part using a group technology code (GT codes). The benefit of this method includes the simplicity of maintenance, but the lack of an on-time calculation of the manufacturing process and the quality of the process plans still rely on the knowledge of a process planner, and it still requires human inputs for the formation of mass data into manufacturing processes.

Fig.2 Variant approach used in CAPP

B. Generative

This involves creating a process plan from scratch for each component without the need of humans. These systems are built to automatically synthesise process data in order to generate a part's process plan. These systems have the logic to build a process plan for a specific component by using a manufacturing database and relevant part description schemes. Generative approach obliterates the drawback of the variant approach in CAPP and bridges the gap between the computer-aided design (CAD) and computer-aided manufacturing (CAM).

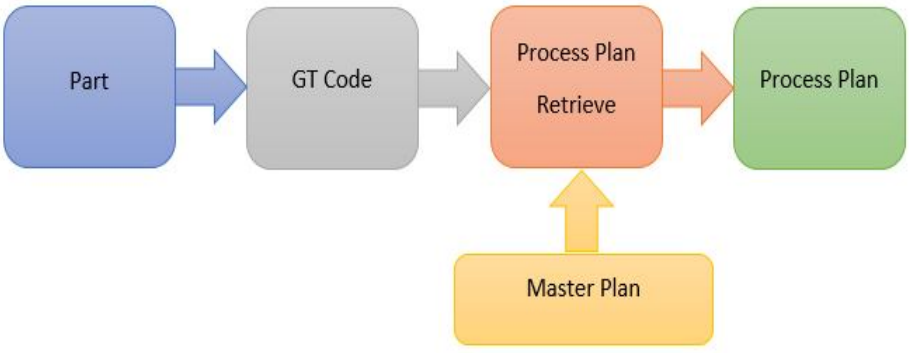

Fig.3 Generative approach used in CAPP

1) Advantages of using CAPP

CAPP has numerous advantages, some of them are listed here

a) Reduction in process planning and production lead time.
b) CAPP ensures process plan consistency.
c) It can give more complete and detailed process plans.
d) It can give faster response to rapid changes in engineering.

e) It caters an improved ability to introduce latest manufacturing technology and rapidly update present process plans so as to utilize the improved technology.
f) Accessing up-to-date information in a central database system can be made available.
g) It results in improved cost-estimation procedures and eliminates calculation errors.
h) It facilitates with production scheduling and capacity utilization of machinery.
i) Makes efficient use of resources leading to reduction of cost.
j) Maximisation of JIT performance.

When compared with manual process planning the CAPP systems have fewer disadvantages:

- When compared with manual process planning initial cost of establishing a CAPP system are high.
- Also, CAPP systems have inability to show special manufacturing techniques.

III. OBJECTIVE

To present a Comprehensive Survey for easy understanding of the past, present and future of CAPP with brief introduction of CAPP approaches, methods, conclusion.

IV. CAPP SURVEY

A. *Brief review of past survey*

1) *1980's: I*n the year 1984, Harold presented the first review on CAPP mainly discussing about developing a generative type automated planning system.[1] In 1988, Ham and Lu presented an assessment of CAPP stating that future research lies on integration of design, manufacturing and artificial intelligence.[2] Next in 1989, 128 systems of CAPP were surveyed by Gouda and Taraman discussing about the four types of CAPP systems namely variant, generative, semi-generative and an expert process planning system.[3]
2) *1990's:* In 1993, Hoda ElMararghy conducted a survey where issues relating to quality and evolving standards were discussed. It also discussed about the major development in CAPP, evolving trends, integration of design, challenges at that time as well as production planning.[4] In 1995, author Kamrani overviewed the techniques used and role of process planning in manufacturing. It also listed the issues and characteristics associated with selection and evaluation of CAPP systems.[5] Same year Leung published a comprehensive review on CAPP where he stated that solid modelling in CAPP system is not sufficient and the future process planning system to be built on AI techniques.[6] A review done in 1996 and presented two years later by Marri and others discussed about the advantages and disadvantages of production planning system along with generative approach for CAPP.[7] Later in 1997, past 8-year survey was done by Cay and Chassapis that provided an overview of manufacturing and feature recognition techniques with CAPP.[8]
3) *2000's:* In 2000, Kulkarni and others presented a review of process planning techniques in layered manufacturing to analyse the situation and suggest future approach of research in this area.[9] In the same year, Tan and Khoshnevis presented a review in integration of process planning and scheduling to discuss the extent of applicability of various approaches and suggest directions for future research.[10] Ahmad and others in 2001 presented current trend in computer aided process planning to classify the presented research work according to their focus.[11] In 2007, Zhang and Xie provided a review on agent technology for collaborative process planning.[12] Professor Hoda ElMaraghy presented evolution and future perspectives of CAPP in 2007-08 to assess the evolution of various CAPP approaches, techniques and their effectiveness in industrial application, future perspective and research. [13]
4) *2010's:* In the year 2010, Li and others presented a review on integrated process planning and scheduling systems which classified the various research work presented and suggested some future trends.[14] In very next year 2011 a critical review of recent developments and future trends in computer aided process planning was presented by Xun Xu and Wang.[15] Three years later in 2014, Yusof and Latif came up with survey on computer aided process planning to classify the focused issues of research work in different areas.[16] Later in same year Isnaini and Shirase presented a review of computer aided process planning systems for machining operation in which discussion of effective parameters relating to development of CAPP systems for process plan for metal removal were highlighted.[17] Mohsen Soori presented application of CAD/CAM system in developing the machining operations using virtual machining in following years 2013, 2014, 2016, 2017 and 2020. Mazin and Atanas in 2018 presented a survey on smart automated computer-aided process planning (ACAPP) techniques which deals with the missing aspects in smart ACAPP generation, the limitations of current systems in recognizing new features and justifying the process selection in CAPP.[18]

B. Present survey

The present survey relating to CAPP methods (past and present) is divided under ten categories to which the related technologies belong and contribution of each method is represented using a figure at last.

1) *Feature Based and Solid model-based Process Planning:* Almost all CAPP systems function on the basis of features and/or require features as an input data. The two approaches to obtaining features are feature recognition and design by features. The feature recognition probes the topology and geometry of the part and determines the existence and definitions of features. While the design by features method involves both adding and subtracting features to develop desired part. In 2017, Vinod V Rampur and other investigated computer aided process planning using STEP neutral file for producing automotive parts from STEP AP-214 of 3D model extracting the basic features of automotive part from STEP AP-214.[19] In the paper by S P Leo Kumar and others in 2014, a new methodology for automatic part feature extraction and CNC code generation for micro features in tool-based micromachining processes was presented.[20] Vamsi Krishna and others in 2011, presented a new idea to generate process plan from feature-based modeling, based on an integrated geometric modeling that proposes both feature-based modeling and its information storage.[21] Chandra R. Devireddy analysed a method of integration of the CAD & CAPP aspects of manufacturing using the idea of Feature-Based Modelling (FBM) and Artificial Neural Networks (ANNs) in year 2010.[22] Patil and Pandey developed an intelligent feature-based process planning system for prismatic parts in 2002.[23] A feature-based inspection process planning system for co-ordinate measuring machine presented by Zhang in 2000.[24] Same year Case and Wan integrated process planning and assembly system to generate new CAD/CAM systems that became capable of assisting in the optimization of product design.[25]

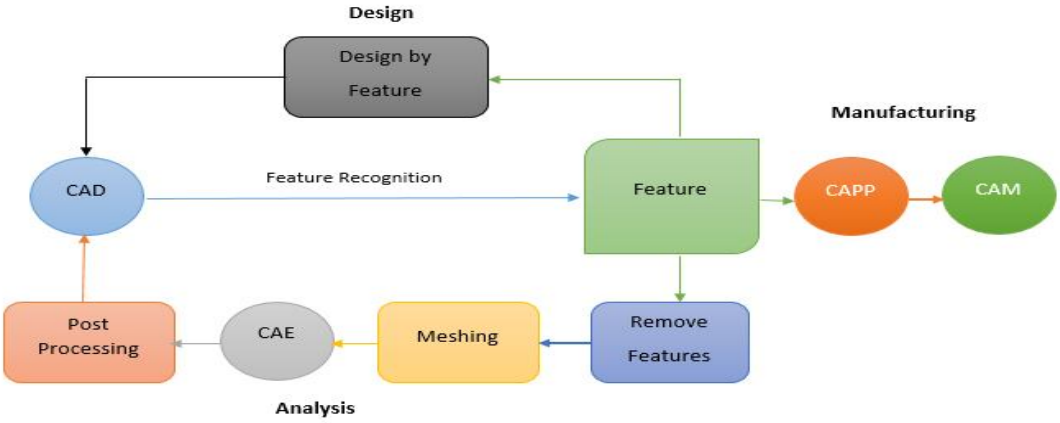

Fig.4 Feature recognition methods in CAPP.

2) *Neural network in CAPP:* It is a network of neuron which are structured in the same way as our brain, it consists of three layers namely an input layer, a hidden layer (which basically of one or more than one layer) and an output layer. The neurons are often called as node. Each node is connected to one another in such a way it resembles a biological neuron and has a corresponding weight and threshold. The chance of obtaining a good result depends upon how dense a network is, i.e., a denser network will provide a high and accurate result. In manufacturing this type of system is used for the selection of machine tools to optimize its performance. The input node in neural network is used to represent its machining part characteristics as well as its operation while on the other hand output node is used to represent specific machine tools which are being used to perform certain operations. Niechen Chena in 2021 came up with research on artificial neural network (ANN) based approach for machining process planning, mostly about the toolpath planning for milling operations.[26] In year 2019, Guang Hu along with others optimized the hardness of SLA printed objects by using the neural network and genetic algorithm.[27] Natarajan and other in 2018 focused on the application and role of artificial neural network techniques in CAPP.[28] In 2017, Izabela Rojek made use of neural network models in CAPP and developed it to aid CAPP for complex real systems.[29] Earlier in 2012, Jun Wang introduced the artificial neural network for manufacturing knowledge modeling and it is represented as neural network weight value matrix, and then forming ANN database to support intelligent CAPP.[30] In 2010, Romdhane and others came up with a model for integration of neural network approach in CAD/CAM for the task of generating a process plan for machining features.[31] While in 2009, Sunil and Pande came up with ANN-based feature-recognition (FR) system, used to recognize complex machining features by analyzing feature topology and geometry.[32]

3) *Optimization techniques using CAPP:* To increase efficiency in process of part production, optimization techniques are generally applied to the CAPP process. Thereby decreasing time and cost of production using the optimized parameters of part manufacturing. In a manufacturing system optimization leads to enhance the efficiency of system by maximizing profit, productivity and quality of product and minimizing the production cost and non-productive time. In 2017 Phung and others presented an effective method of operation sequence optimization in CAPP based on modified clustering algorithm that highlighted the sequence and compared their traveling costs to choose the optimal operation which resulted in the minimum traveling cost in the sequence.[33] Earlier in 2016, Mitin and other investigated on mathematical modelling in the computer aided process planning.[34] An Optimization of operation sequencing in CAPP using simulated annealing technique (SAT) presented by Nallakumarasamy in year 2011 described techniques to obtain optimal sequences in a single run with lesser computational time.[35] In 2009, Shao came up with a new integration model with a modified GA-based approach to facilitate the integration and optimization of various CAPP systems.[36] Same year Salehi and others optimized machine tools, cutting tools and tool access direction by using the genetic algorithm.[37] A year earlier in 2008, Siva Shankar optimized process parameters for rotational components that lead to reduce machining time and cost as compared to handbook readings and traditional practices.[38]

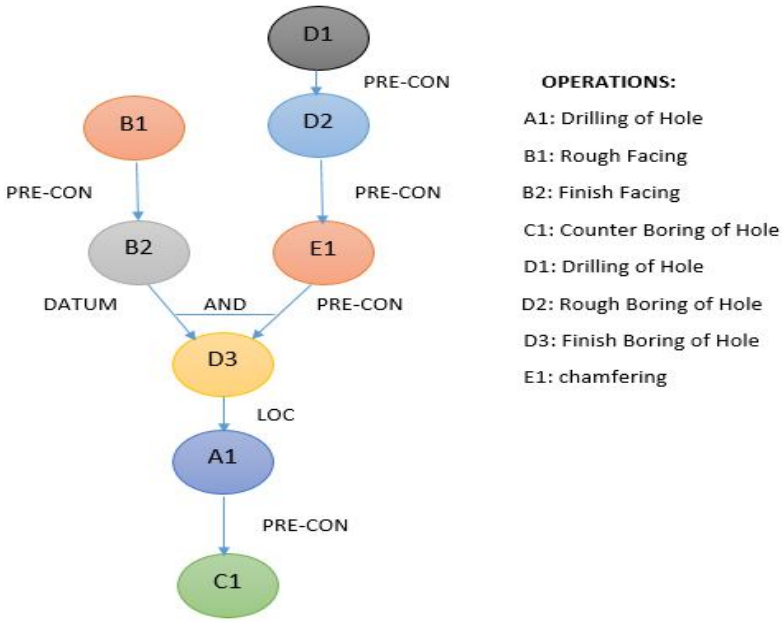

Fig.5 Optimization of operation sequencing in CAPP (Super hybrid genetic algorithms

4) *Fuzzy logic in Process Planning System:* The various decision-making in the real world such as process planning takes place in a domain in which goals and constraints are fuzzy (not known accurately). So, approximation techniques are used to obtain a logical model in a real environment. This theory deals with similar type of problems by transforming human knowledge to mathematical formulae and puts it into the system together with other information like mathematical models and sensory measurements in which goals and constraints can be transformed to model by fuzzy sets. In 2014, Pendokhare developed a fuzzy logic model for drilling operations to select drilling speeds for different types of materials. The fuzzy relationship between various cutting materials, various apertures and feed rates is used to analyse and evaluate various problems between the hardness of a given material and the drilling speed, and these results were given.[39] In 2013, Amaitik developed a logic model with fuzzy characteristics that can help select machining parameters such as cutting speed and feed rate in the automatic CAP system.[40] In 2010, Mula and others studied the effectiveness of fuzzy mathematical programming for any production plan where the demand in the supply chain is essentially fuzzy.[41] Three years ago, in 2007, Leung and others introduced a powerful optimization model for production planning problems in multiple locations in any unsafe environment.[42] In the same year, Aliev and others studied the fuzzy genetic method of aggregate production planning and distribution in supply chain management.[43]

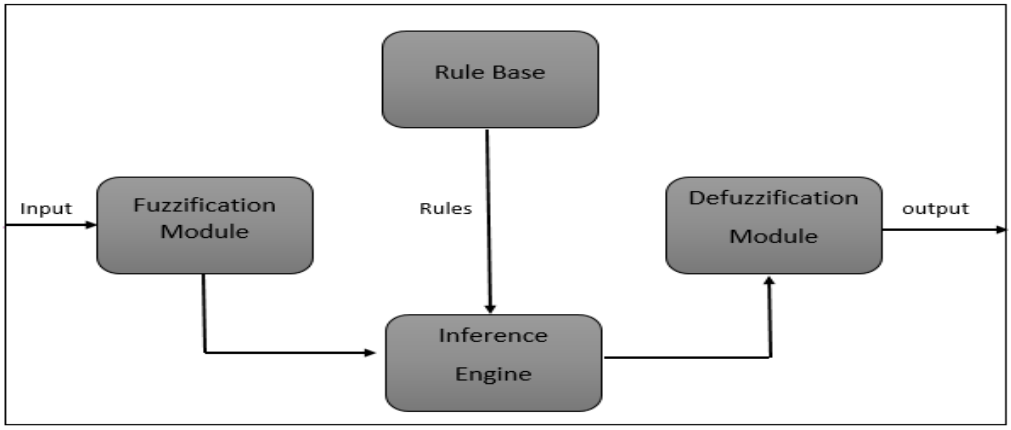

Fig.6 Fuzzy logic architecture

5) *Knowledge based CAPP System:* In this system the process planning to a large extent depends upon the past experience of a process planner or expert, therefore this system is also known as knowledge-based system. In traditional approach the decision of process planning surrounds entirely around a process planner. The planner uses his skills based on past experience to generate processing steps required in manufacturing. There are numerous disadvantages of this system which includes; inconsistency, dependency on skilled experts, time consuming etc. To overcome this bottleneck, it got automated with the help of computers so that better decision-making function can be incorporated in process planning. S P Leo Kumar in 2018, made an effort to review knowledge based expert system applications in manufacturing planning.[44] In 2015, Ravi and others presented knowledge-based computer aided process plan and computer numeric control code generation for the development of a generative process planning methodology used in automated generation of CNC codes for 3 axis milling centres with the CAD geometry as the only primary input.[45] The hybrid method of knowledge representation in a computer aided process planning knowledge-based system brought up by Grabowik and others in 2012.[46] An overview of the CAPP field based on an integrated approach that combined technological and business considerations was studied and presented by Denkena under title knowledge management in process planning in year 2007.[47] Previously in 2001, Law in his presentation investigated object-oriented knowledge-based computer-aided process planning system for circuit boards manufacturing.[48]

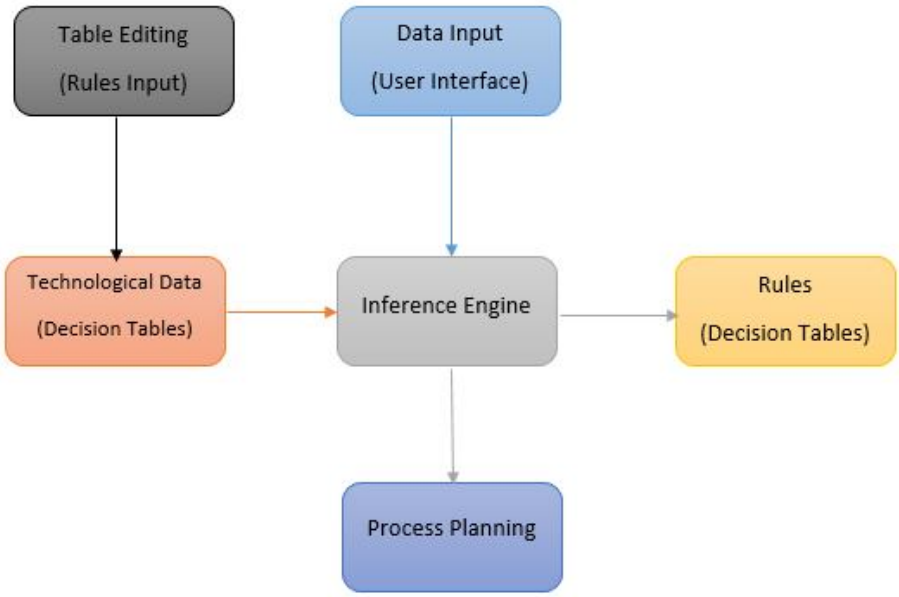

Fig.7 Knowledge based CAPP system for drawing dies.

6) *Web Based Technologies in Process Planning:* The Manufacturing application of web-based technology leads to interconnection and automation of various infrastructure mainly machine control unit in the shop floor area as well as ERP in production process. The integration of manufacturing and production can be carried out with the help of web-based technology but for that it requires updated infrastructure or some form of investments for creating adaptable infrastructure. In 2019, Murena and others used web-based process planning system to effectively bend varieties of sheet metal product using various bending press machine.[49] Mijodrag and others in 2017, presented e-CAPP in which authors discussed about a system for distributed collaborative system which assisted manufacturing enterprises and experts in discussing, suggesting, evaluating and selecting best process plans for manufacturing parts of same family.[50] Shan Wan and others in 2015 investigated a web-based process planning for machine tool maintenance and services and presented a collaborative maintenance planning system resulting to manage information and knowledge to support decision making.[51] A year earlier in 2014, Nagaraj and others implemented the web-based manufacturing process planning workflow in pressure die casting industry.[52] In year 2013, an Internet-based CAD/CAM/CAPP prototype system for the remote manufacturing of different mechanical components was evolved.[53] Earlier in year 2009, Agrawal and others addressed the DPP problem in the e-manufacturing by presenting a multiagent system consisting of three autonomous agents namely global manager, design, and optimization.[54A] In year 2008, Hu and others presented their work and tried to solve the operation sequencing problem for web-based process planning.[55]

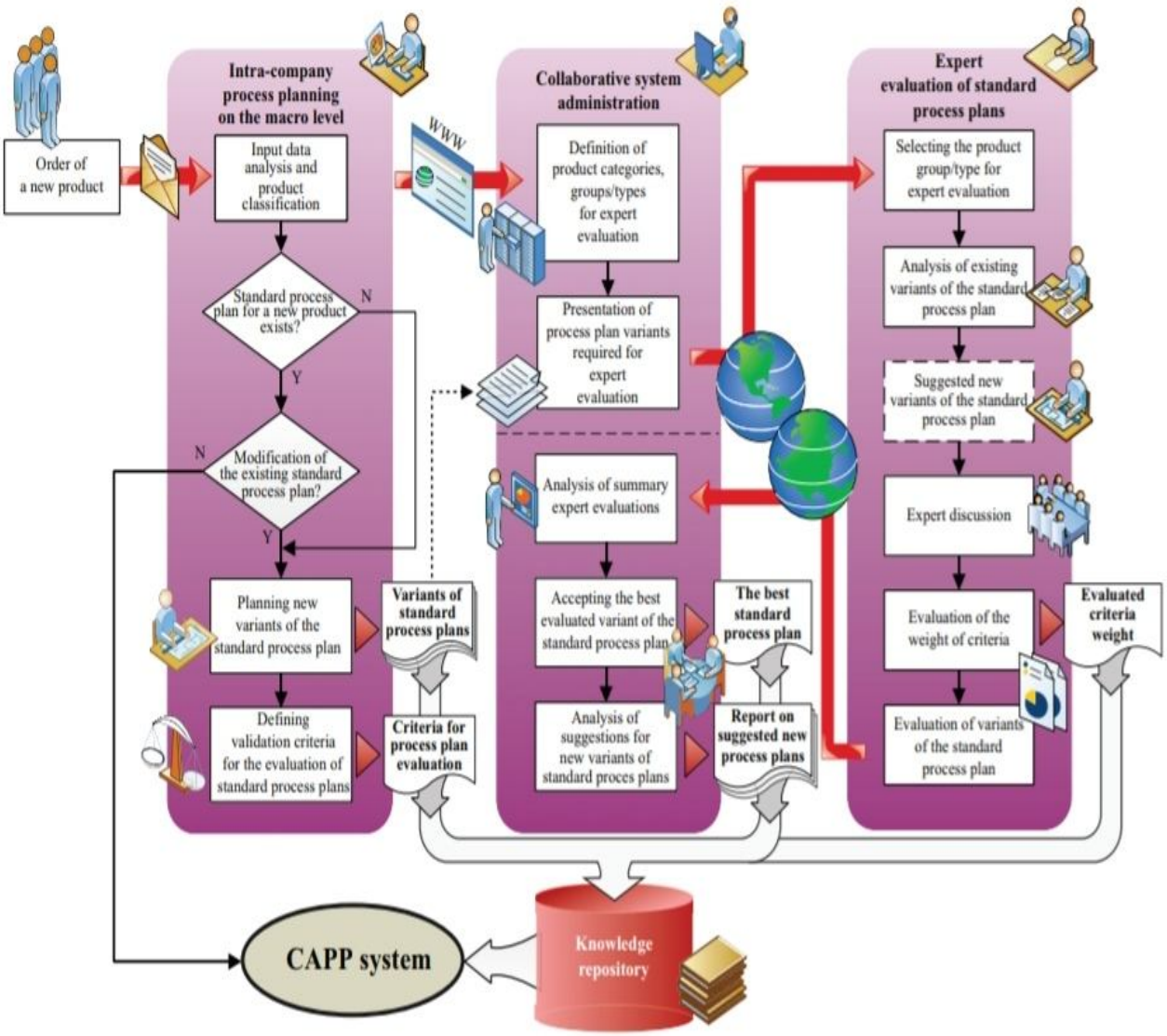

Fig.8 Web based technology in process planning. [a]
Source: Mijodrag et al. (2016)

7) *Hybrid Manufacturing Process Planning System:* In hybrid type two or more manufacturing process are integrated together e.g., Additive manufacturing and subtractive manufacturing has gain considerable recognition in recent years. The process extracts the benefit of individual processes while overcoming their limitation at the same time. With the integration of CAPP and Hybrid manufacturing, process planning has been optimized to a great extent. Evolution of computer-aided process planning for hybrid additive/subtractive process presented by Osama and others in year 2020 which discussed mathematical models to optimize part orientation as well as minimize additive and subtractive times. The feasibility and capability of the proposed approach and the optimized CAPP for the hybrid process are explained in a case study.[56] Ann-Kathrin in 2019, investigated a hybrid-manufacturing concept where standardized base parts were produced in large volume production first and then assembled to finalize by additive and subtractive manufacturing.[57] In year 2018, Basinger and others came up with an analysis in the form of a modular computer-aided process planning (CAPP) system for additive-subtractive hybrid manufacturing used for pockets, holes, and flat surfaces. [58] Newman in 2015 developed process planning for additive and subtractive manufacturing technologies.[59] Earlier in 2012, Zhu presented a novel process planning approach for hybrid manufacturing consisting of additive, subtractive and inspection processes.[60]

8) *Artificial Intelligence (AI) in CAPP:* In its simplest form, artificial intelligence is a field, which combines the application of computer and large datasets, to solve a given problem. In this methodology machines learn from experience, and then adjust to new inputs and perform the task more accurately and efficiently. With the help of this methodology, a large set of data is processed and patterns in the data are recognized to accomplish certain tasks. In 2020, Raffaele and others came up with a research to analyze, the scientific literature relating to the application of artificial intelligence and machine learning (ML) in various industries.[61] Zhang Bo in 2016 presented his work titled research into technology decision methods of CAPP Artificial Intelligence that discussed the method of automatic processing in CAPP and established an effective intelligent process decision-making system.[62] In year 2012, Prakash and others developed a mathematical model to analyse the randomized CIM environment using advanced CAPP systems.[63] Stryczek in 2007, reviewed computational intelligence in computer aided process planning mainly discussing about elements of a typical CAPP system such as FBM, part feature extraction, integration, process planning system development resulting to develop the CAPP systems.[64] Earlier in 2000, Chang and Chang generated multiple process plans using an integrated artificial intelligent, fuzzy logics.[65]

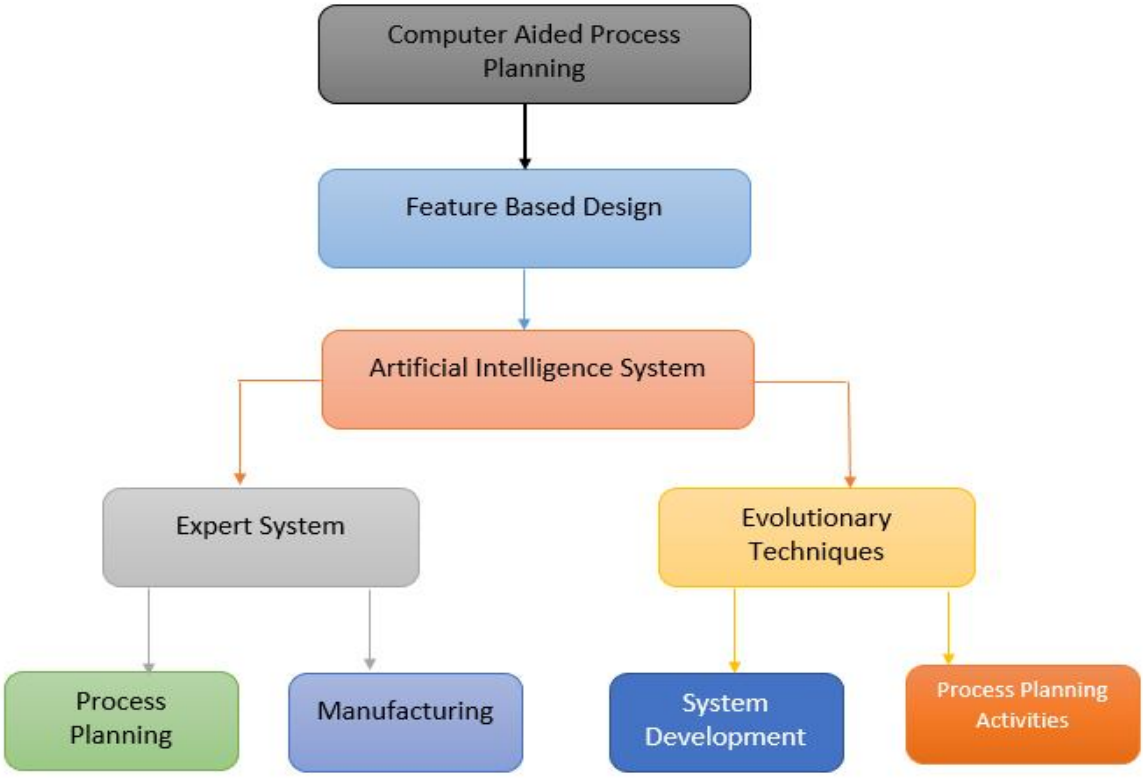

Fig.9 AI systems application in process planning and manufacturing.

9) *Virtual machining system for CAPP:* Virtual machining is defined as the application of computers to simulate and model the use of various machine tools for different manufacturing processes. This method replicates the behaviour and show the errors of a real environment in virtual reality systems. This leads to manufacture of products without its physical testing on the shop floor. As a result of which both time and cost of products can be reduced to a significant level. With the help of this it becomes easier to evaluate geometrical and dimensional flaw as well as cutting forces in machine tools. Parag and others in year 2017 presented their research titled computer numerical control machine tool information reusability within virtual machining systems in which authors reviewed research trends in the domain of virtual machining and later discussed how much of research has been taken on board by software vendors in order to facilitate machine tool information reusability.[66] Same year, wang and others investigated practical models of the cloud-based system and distributed process planning services were developed accordingly.[67] In 2013, Kim and Woo presented their work and developed a virtual corner detection system in their study to modify the process planning of parts using virtual machining system.[68] Earlier in year 2010, Ahmad and others presented applications of genetic algorithms in process planning which they came up with a systematic method for automatically selecting an optimal tool sequence for 2.5-axis pocket machining in their study.[69] Rajeev and others in 2008, generated the algorithm for optimal or nearly optimal identity of sequence of operation of prismatic part of minimum production.[54B] In 2000, Narita investigated a virtual machining simulation to analyse and optimize the cutting tool paths for milling operation in virtual environments.[70]

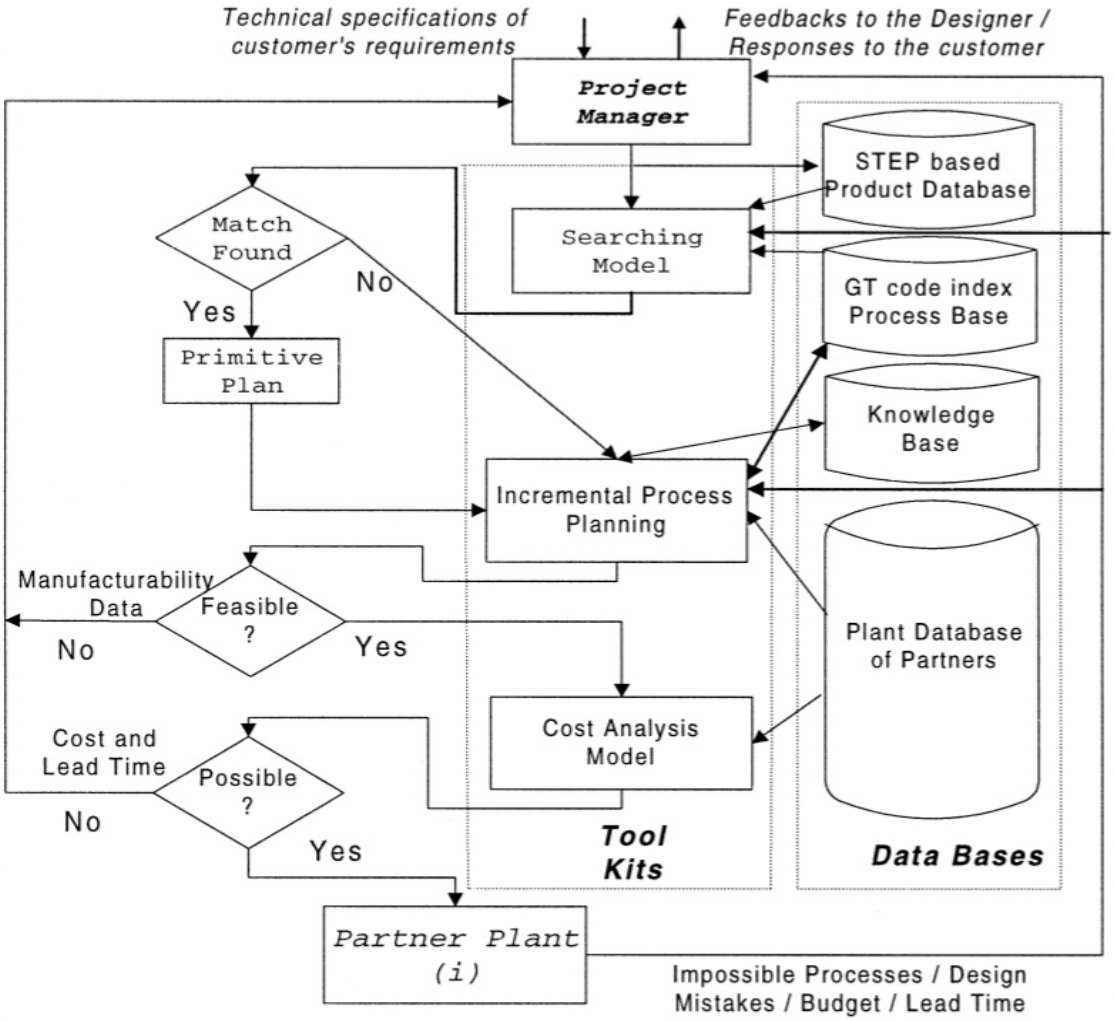

Fig.10 A reference architecture of CAPP system in a virtual company. [b]
Source: Yiliu Tu et al. (1998)

10) *STEP-Compliant CAPP:* Although with automation, a higher degree of accuracy in Design and manufacturing areas is achieved sharing of information between different system and software including CAPP were still lagging behind, to overcome this limitation the International Organisation for Standardisation (ISO) developed a methodology by which it is now possible to share the information between numerous other applications. Yu Zhang in 2021, presented an Intelligent feature recognition for STEP-NC-compliant manufacturing which was based on artificial bee colony algorithm and back propagation neural network.[71] In 2019, Vinod V Rampur and other came up with a computer aided process planning using STEP neutral file that proved useful for automotive parts.[19B] In 2012, Han and others came up with his work titled a framework of STEP-NC manufacturing system integrating CAD, CAPP, CAM and CNC in which a STEP-NC manufacturing system using networked manufacturing systems was presented.[72] In 2005, Amaitik proposed a STEP-based feature modeller for computer-aided process planning to be used for prismatic part.[73]

V. CONCLUSIONS

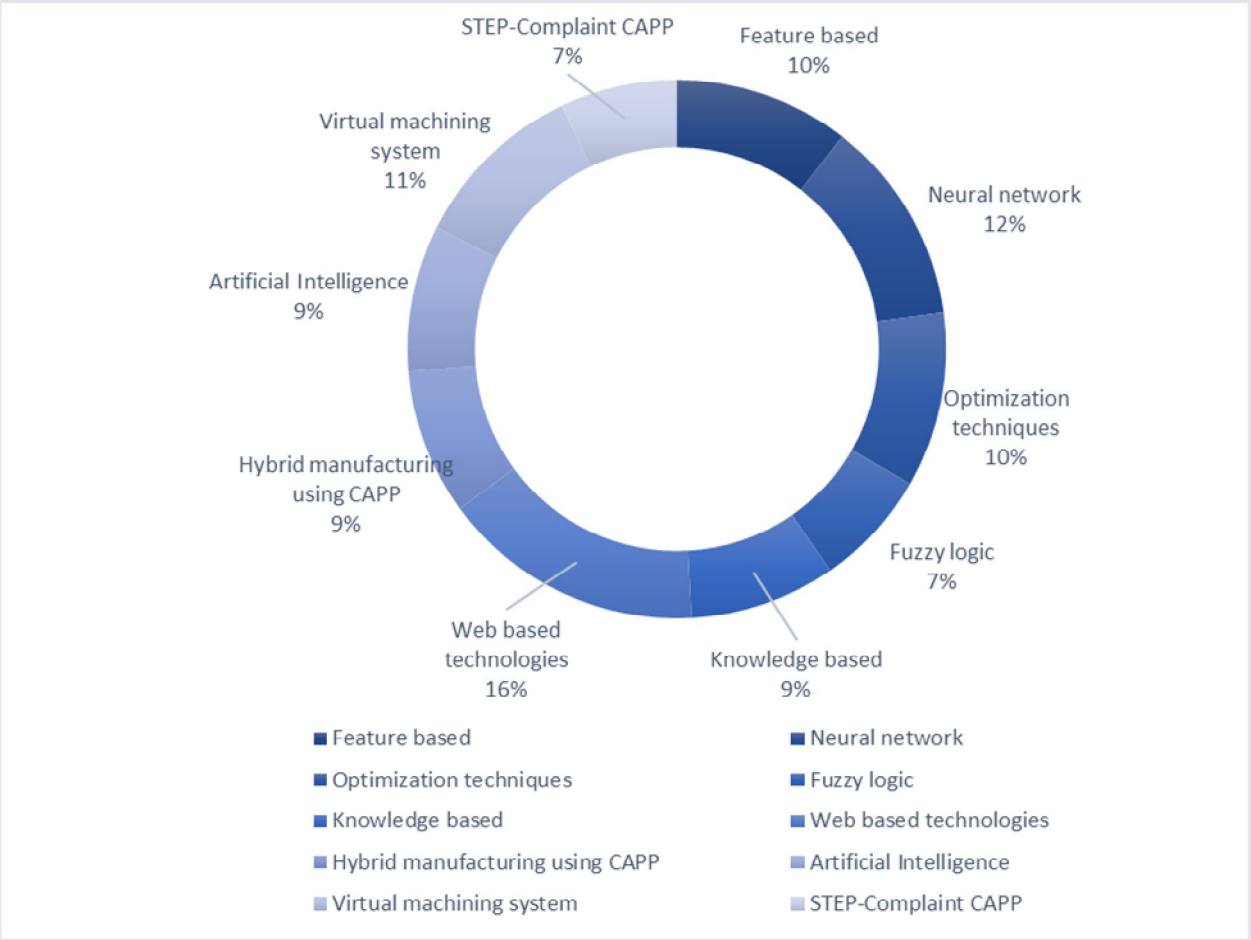

Fig.11 Contribution of various methods in the presented survey.

CAPP is need of the hour, as with the rapid growth and technological advancement in the field of manufacturing where to meet high demand requires high production rate. This demand can be fulfilled by integration of computer aided design (CAD) and computer aided manufacturing (CAM). So, at present there is a need of CAPP in all those manufacturing system which can justify the cost of production. Also, new demands of CAPP systems are created day by day due to increasing part complexities and rapid manufacturing developments. Nowadays, CAPP systems are connected by using web to share data between different steps of process planning.

In this survey, it has been found that CAPP tries to resolves most of the issues pertaining to planning, operation, setup, scheduling, machine selection, tool selection, job sequencing, reorganization, tool path generation, optimization and various others. Various research papers from different journals were studied to present the contribution of feature based and solid model-based process planning, neural network in CAPP, optimization techniques using CAPP, fuzzy logic in process planning, knowledge-based CAPP system, web-based technologies in process planning, hybrid manufacturing process planning, artificial intelligence in CAPP, virtual machining system for CAPP and STEP-compliant CAPP. Taking in account the number of prominent journals in various different years in and after year 2000, the contribution of each ten methods is displayed in figure 11.

VI. SUGGESTIONS

Manufacturing world day by day is moving towards more advance, intelligent and flexible technology. As a result, there is demand for advance and intelligent CAPP. While fulfilling these demand, global environmental issues pertaining to environmental changes should be taken into account. In future, the key area of research for CAPP should be such that it contributes towards green manufacturing environment, less energy consumption, non-traditional manufacturing processes, rapid prototyping process, micro manufacturing and nano manufacturing.

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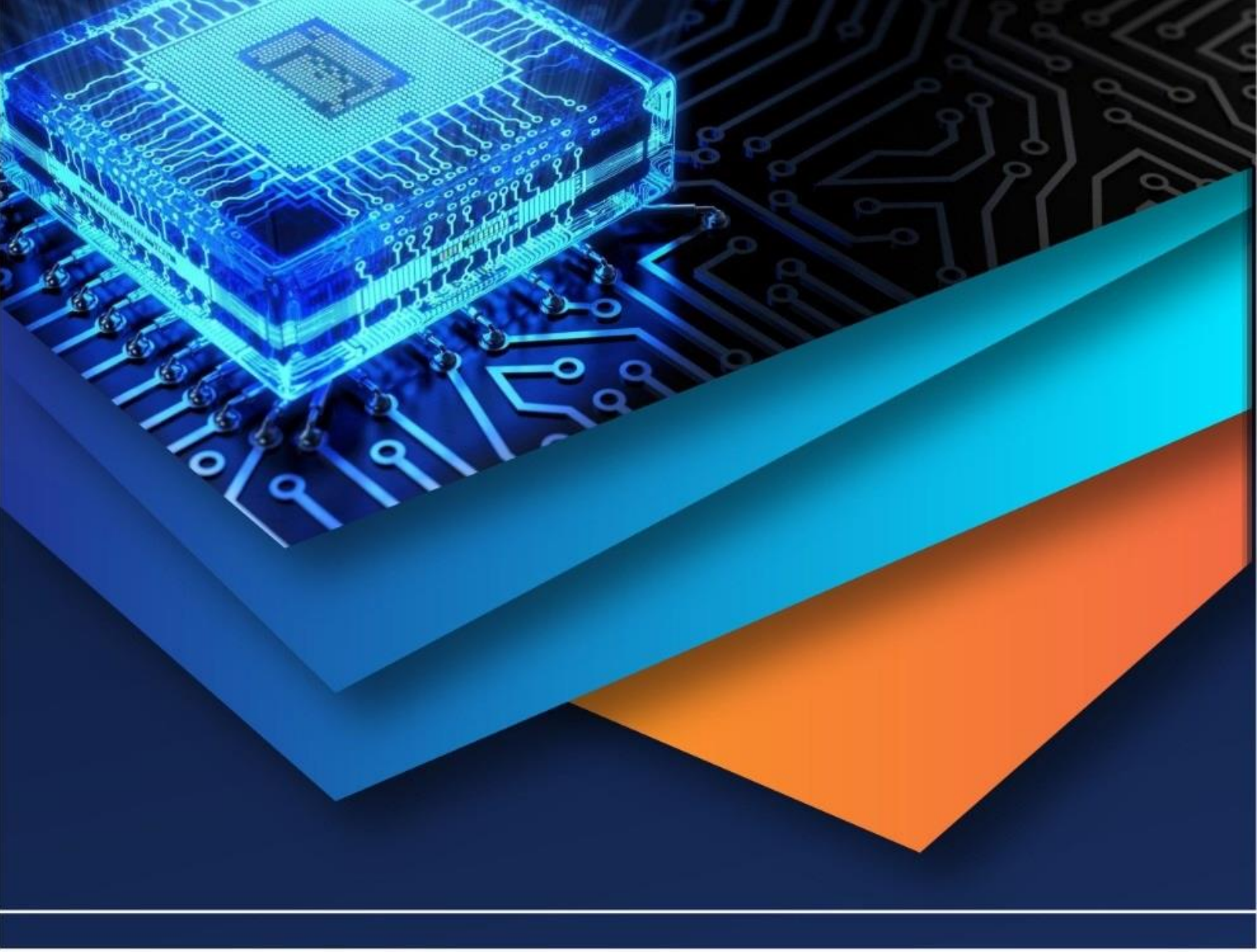

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