Collaborative Information System Architecture for CAD/CAM in New Product Development Based on STEP Standard

Mahmoud Houshmand and Omid Fatahi Valilai

***Abstract*—In today's competitive market, information technology tools play a most important role in new product development. Integrated design includes CAD, process planning and CNC code generation. The commercialized CAD/CAM software solutions and industrial systems can be acquired readily. These solutions or systems, however, cannot connect together in a seamless way, that is, they cannot fit in integrated environment. Different CAD/CAM Application software need supports for data exchange in manufacturing enterprises. This article reviews the different architectures of integrated and collaborative information systems architectures. The reviewed architectures reveal that comprehensive interoperable CAD/CAM application software should be developed. Most of current architectures do not support integration of data; they can't connect different CAD/CAM application software seamlessly for data interchange based on STEP Standard (ISO 10303) and can't enable the CAD/CAM application software to collaborate together. Considering these lacks, this article proposes architecture for a comprehensive interoperable CAD/CAM interface; and discusses the different aspects of this architecture. The architecture consists of several layers. These layers support all CAD/CAM application software engaged in product development. The CAD/CAM application software exchange their required information collaboratively based on their own data structure. The architecture layers convert the application software' processed data to STEP based data model. They store the processed data in an integrated database; and vice versa, the layers retrieve the data to the CAD/CAM interface's data structure.**

***Index Terms*—CAD/CAM, ISO 10303(STEP Standard), Collaborative information system, integration.**

I. Introduction

In today's competitive markets where the customers' believes and needs are the major components of a product, understanding and developing efficient new products makes the winners of the enterprises. For a new product to achieve significant and rapid market penetration, it must match such customer requirements as new features, superior quality and attractive pricing [1].

The importance of new product development (NPD) has grown dramatically over the last few decades, and is now the dominant driver of competition in many industries. In industries such as automobiles, biotechnology, consumer and industrial electronics, computer software and pharmaceuticals, companies often depend on products introduced within the last five years for more than 50 percent of their annual sales [2]. The enterprises try to suggest successful products. However, new product failure rates are still very high. Many R&D projects never result in a commercial product, and between 33 and 60 percent of all new products that reach the market place fail to generate an economic return [2].

A crucial problem in the development of new products is to reduce the time required to design and manufacture while still maintaining high quality and minimum development cost. To achieve this, input product data from customers, suppliers and experts are essential for all parties. The overall design process must be well orchestrated and integrated [3].

A. Collaborative CAD/CAM in new product development

Planning and developing the new products are considered as one of the most important part of the products life cycle. However, so many problems encounter when attempts are done for new product design [4]. These problems usually are related to the exchange of product data and information between different parts of the enterprises [5].

An intelligent interface between CAD and CAPP systems is imperative because the CAPP systems depend on correct data obtained from CAD systems to perform precise process planning [6]. Considering the CAD/CAM systems that use different data structures for processing; one of the most important weaknesses of these systems is due to their nonintegrated infra structures and information [5]. In general extracting manufacturing information from CAD database is not adequate, since current CAD systems do not provide all manufacturing and process planning data. Part model should include not only geometric and topological information but also technological information namely features, surface roughness, hardness, etc. for CAM systems [7]. The researchers express that the problem is the accurate and meaningful: product data is not visible to the personnel that need it [8].

Teams usually use their tools for work that generates product data in various formats. These formats make a problem for collaborative product development. This problem is a common problem just because there are so many different tools to work on the new products design and old designs revisions, it is believed that there are so many different CAX on the market; it is evident that the Product Data Technology objectives can only be realized via standards [9].

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The extended enterprises involved with product development processes are heterogeneous environments beset with disparate CAD models [10]. In fact, the trend towards global manufacturing exacerbates it - producing a constantly shifting web of product development and delivery partnerships. The lack of effective interoperability among the extended enterprise threatens product quality, drives up costs, and lengthens time-to-market [10].

This is a new paradigm for CAD/CAM computer systems based in global environments, network-centered and spatially distributed, enabling the development of activities using e-Work. This will allow the product designers to have easier communication, making it possible the sharing and collaborative design during product development, as well as the teleportation and monitoring of the manufacturing equipment [11]. For achieving to collaborative works on CAD/CAM product development so many standards for data exchange have been developed and revised, one of these standards is the STEP (Standard for the Exchange of Product Model Data) which is an international standard, which addresses the representation and exchange of product data [12].

Since the mid-1980s, the international community has been developing the ISO 10303 set of standards, well known as STEP (ISO 10303-1 1994), which has its foundations in many of the earlier aforementioned standards. The STEP standard is divided into many parts, i.e. Description Methods, Information Models, Application Protocol (AP)s, Implementation Methods, and Conformance Tools. The Information Models and Application Protocols describe the data structures and constraints of a complete product model [13].

STEP will enable us to iterate designs based on manufacturing suggestions, then evaluate and analyze the results before manufacturing the pieces. It also offers a tremendous benefit for exchange and managing information from several engineering and manufacturing disciplines in an effective way [14].

What major factors are crucial factors in a successful collaborative CAD/CAM product design and development?

The answers may be an integrated Product information system to be able to manage and execute the product development processes. The sample way for doing the regular product development plans is to make the steps of achieving to that aim in an experienced framework called the new product methodology [15]. By the integration of design and manufacturing enterprises can achieve significant benefits such as reduced lead times, increased quality of the product and process, increased profits for the whole supply chain, improved values for clients, users and society [16].

Successful companies in the business world constantly operate in a state of innovation in terms of products they manufacture. They frequently introduce new products or modify and improve existing products feature as needed and desired by the customers [17].

B. *The proceeding research*

This article reviews CAD/CAM information systems that store, manage and process the product data.

It is considered that the systems should support different CAD/CAM software systems in a collaborative environment. In addition, the article reviews the integration of 'product data' based on STEP standard.

Considering the weaknesses of current architectures, the article proposes the structure of a comprehensive CAD/CAM information architecture. Furthermore, it discusses the abilities of proposed system for integration of CAD/CAM product development in an interoperable environment based on STEP standard.

The architecture of a collaborative information system should be capable of linking different CAD/CAM application software in a flexible manner based on their own data structure. The architecture consists of several layers. These layers enable different CAD/CAM software systems to collaborate with each other.

II. An Overview of CAD/CAM Collaborative Information Systems

"**Collaborative multi-agent systems**" is the application of distributed artificial intelligence methods, namely collaborative multi-agent systems in designing. This system is named Multi-Agent System for Computer Aided Process Planning (MASCAPP) [18].

The framework of this system is explained in the Fig **1** and the design of its manufacture chain has been shown in Fig **2**.

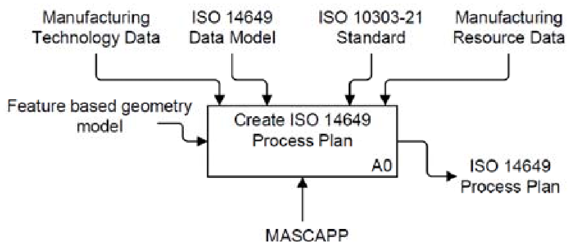

Fig 1. Multi-Agent System for Computer Aided Process Planning (MASCAPP) system framework [18].

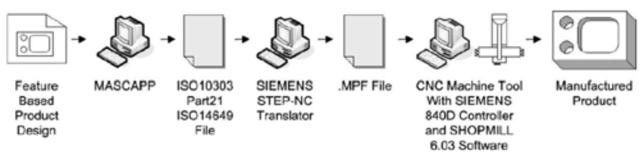

Fig 2. Multi-Agent System for Computer Aided Process Planning (MASCAPP) design to manufacture chain [18].

The structure of this architecture considers a feature based product design [18]. It can be applied to the current systems, which work with software, and applications that support feature based modeling. It results inflexibility where input design modules are not based on feature based modeling. The security of information flows have not been foreseen in the architecture. This architecture can only work in integrated systems that all suppliers, customers and other stockholders work on a unit database. All the information is shared and can be accessed by all. It is common procedure in integrated information systems that different activities in product design and process planning are separately distributed in different location, so different databases can be used by different stockholders to work with the product data and information.

"**STEP based Engineering Data Management (EDM) System**" is the data management system with an integrated data base [4].

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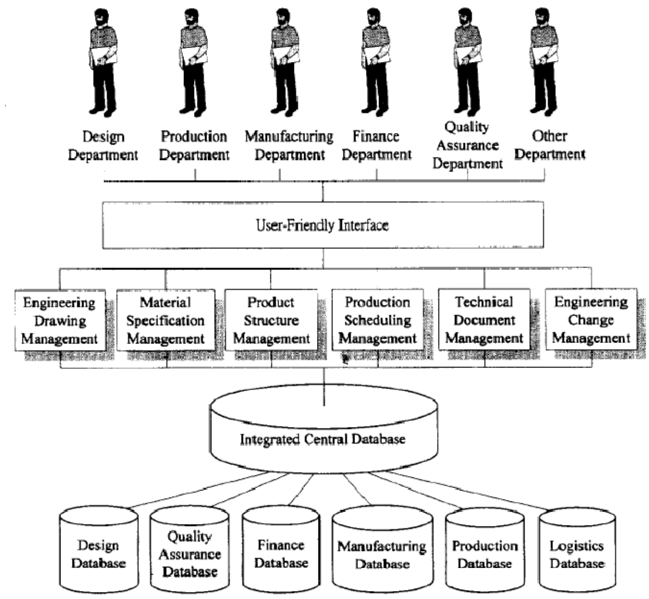

Fig 3. Representation of Engineering Data Management (EDM) system [4].

The Architecture of this system is shown in Fig **3** and the implementation architecture of the engineering data management system is shown in Fig 4. The security of data and information within the system has not been constructed. Considering the information flow and clients that works with the information, there is no flexibility for other CAD/CAM application software that want to join the information system. The architecture lakes for supporting collaboration among CAD/CAM/CNC devices. There is no mechanism to enable flexibile support of CAD/CAM application software with different data structure. The platform can not integrate the CAD/CAM activities based on STEP standard because the management areas are not compatible with STEP application protocools 203,224 and 214.

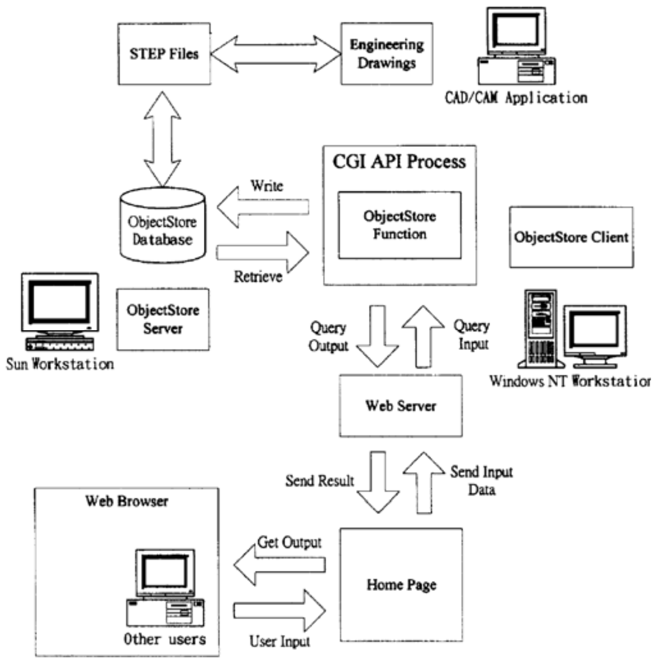

Fig 4. Architecture of implementation of the engineering data management (EDM) system [4].

"**A STEP-based manufacturing information system**" is an information system with Data base structure based on STEP data model structure [19].

The proposed application data access to integrated information system is shown in Fig 5. There is no mechanism to enable collaboration among different CAD/CAM/CNC application software. The architecture states that different CAD/CAM/CNC application software with different data structure can interchange data and information with platform, but there is no element in the platform structure to enable different CAD/CAM application software to collaborate with the system.

The system can not help the distributed enterprises to manage their CAD/CAM application software collaboration. New CAD/CAM application software can not join the architecture for collaboration.

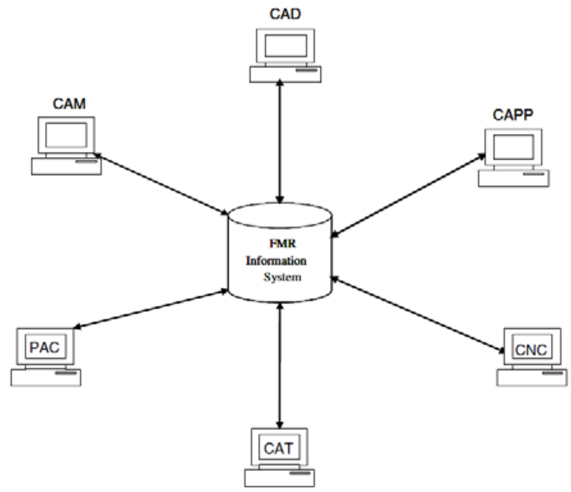

Fig 5. Applications access data from a flexible manufacturing resources information system [19].

"**Steel bridge information management**" the system that is the data management system with an integrated data base for Steel bridge information management system [20].

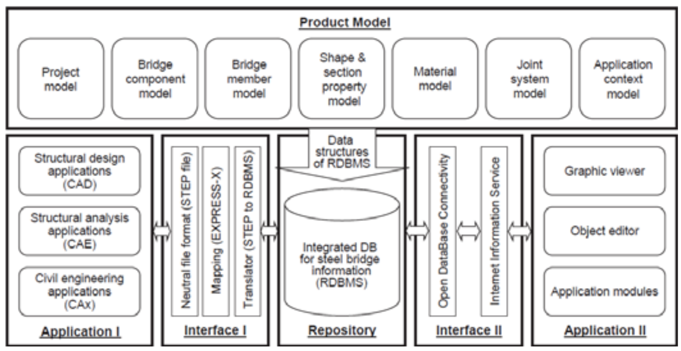

Fig 6 : A framework for steel bridge information management [20]

The framework for this system is shown in Fig 6; the architecture can support data integration but the data structure of STEP file formats should be turned to the RDBMS (Relational Database Management System) format data structure. Application software with different data strucure can not collaborate in this architecture. They should support STEP data structure.

The architecture didn't propose solution for process planning. The system arcitecture can not achieve to CAD/CAM collaboration.

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"**Intelligent agent**" An intelligent agent that was developed for Computer Aided Process Planning in intelligent manufacturing environment work. This agent can take a STEP file as input, and has the capability of generating a machining process plan to manufacture the part modeled in the file [21]. The architecture of this system has been shown in Fig 7.

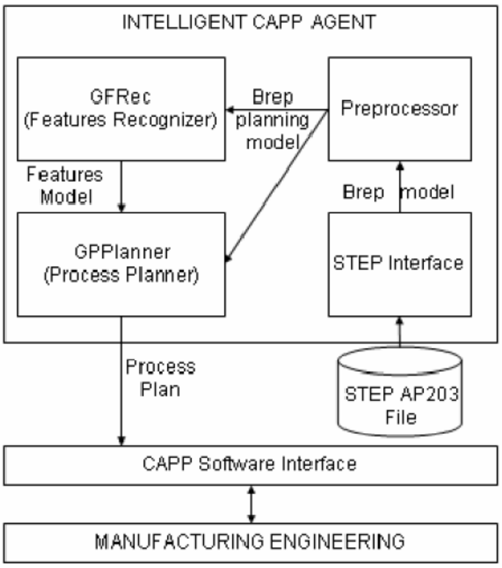

Fig 7. Intelligent agent System architecture [21].

As seen in the architecture the application software for STEP data structure can obtain and convert the data to data model. But the information flow is in one direction. So the data that have been used and processed by CAPP Software interfaces cannot be processed back. The system has no support for collaborative processes that uses the other STEP data structure and even other data model languages. Other CAD/CAM application software should always use the specific data model of graphplanner in order to communicate and collaborate in the system. There is no felexibilty to accept other CAD/CAM software data structures.

"**Prototype wire EDM system**", is A prototype STEP-compliant wire EDM system that uses AgieCharmilles controllers [22]. The architecture of this sysstem is shown in Fig 8. In this prototype system, SolidWorks was used as the design tool to construct solid models. An additional model, which provides STEP-NC supports, was constructed in the AlphaCAM system. The design data are then translated into ISO 14649 files through AlphaCAM and a STEP-NC data generator. Two different systems have been implemented on the shop floor. In the first system, STEP-NC data were translated into a native CNC program for AGIE AGIECUT, a traditional CNC controller through a front-end PC which has a STEP-NC interface and a postprocessor implemented. In the second system, the ROBOFIL 340 from Charmilles implemented a STEP-NC interface within the controller so that it can directly accept STEP-NC programs [13]. The system can only collaborate with Software applications that use Solid work data structure. There is no chance for other Process planning Software applications fro collaboration. The system only works with its ALPHA CAM process plan method. The architecture is not capable of accepting the new Software applications easily.

"**CAE system architecture for support multiple viewpoints**" is the architecture which has been discussed in an information sharing research for CAD/CAM systems [3]. The architecture of this system has been shown in Fig 9. Each of application areas has been supported by an independent single view of the product. The architecture considers the product views interdependent. Fig 9 provides a representation of MOSES (Model Oriented Simultaneous Engineering System). The architecture states that the application should support each other for collaborative work.

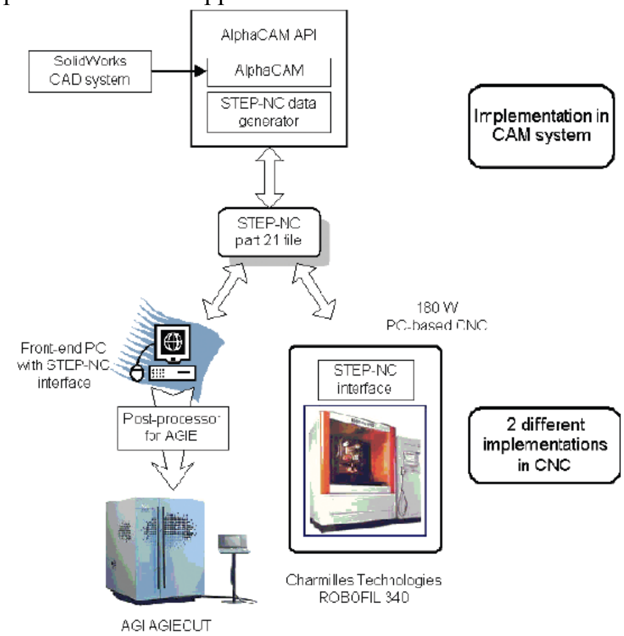

Fig 8 : Prototype wire EDM system Architecture [22]

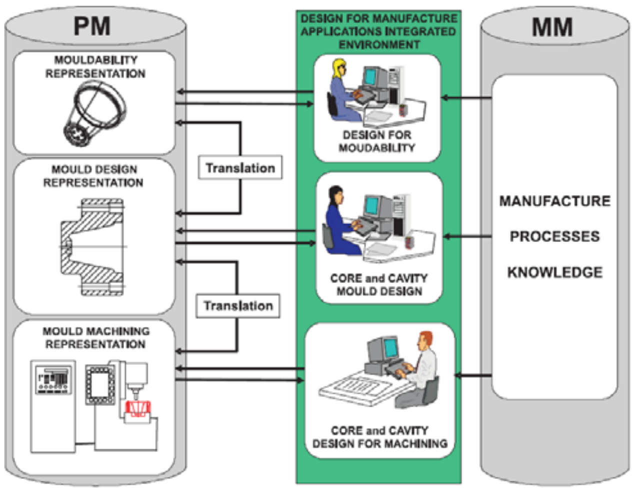

Fig 9 : CAE system architecture for support multiple viewpoints [3]

Every software application should support the other Software applications data structure for collaboration. The joint of new software application needs that it supports all other applications data structure. The architecture insists on an integrated environment but does not define any data structure and mechanism for enabling integration. There is no mechanism to enable the CAD/CAM application software collaboration.

"**Incremental Simulation Modeling for Internet Collaborative Design**" is the system architecture, introduced for collaborative design by web [23]. The architecture of this system is shown in Fig 10. In this model, any model changes need to be updated at the server and broadcast to the client for updating display. Local updating is a strategy for making incremental changes to a geometric model. Only those parts of a model that are affected by creations and modifications are recomputed and re-exchanged between the server and the client, which considerably increase efficiency compared to updating the complete model and its display.

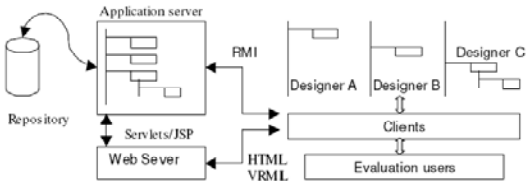

Fig 10: Incremental Simulation Modeling for Internet Collaborative Design architecture [23]

The Software applications in this system should support a data structure. This makes the architecture inflexible to enable other Software applications to collaborate with each other based on their own data structure. New Software applications with different data structure cannot join the system. Although the architecture insists that it considers the user evaluation, the security of data flow is not properly achieved. The architecture does not support CAM integration with CAD activities. The CAM software application cannot collaborate in this architecture.

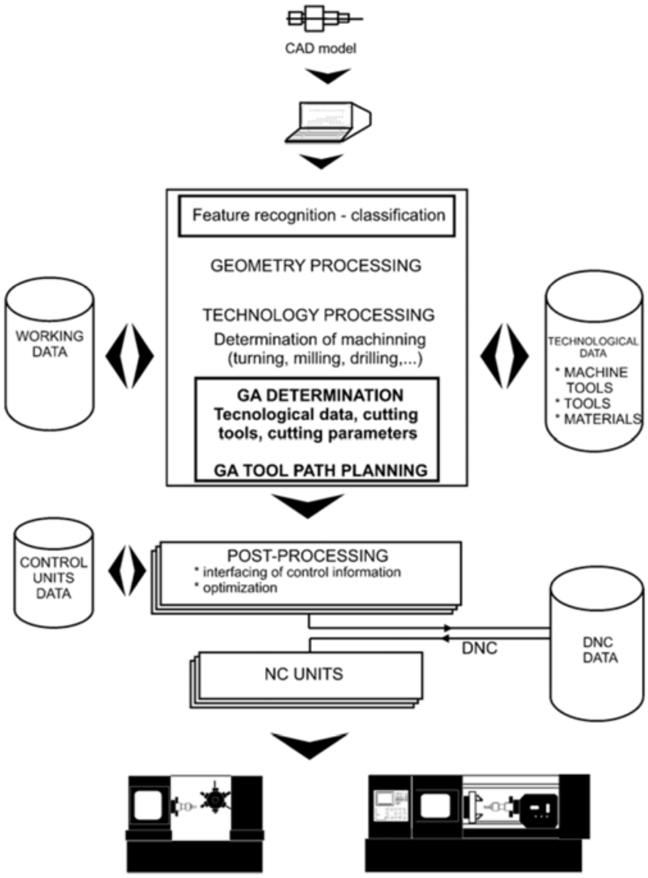

Fig 11 : Intelligent CAD/CAM system Architecture [24]

"**Intelligent CAD/CAM system**" is the integrated CAD/CAM system for intelligent CAD/CAM design [24]. In this system, the initial 3D-parts are represented by boundary representation (B-rep.). The Recognizer is able to recognize many different types of features out of which special attention is given to the recognition and classification of explicit features. Output data of the first part from Recognizer represent the input for the next part, the Searcher. It takes the evaluated geometric data from the Recognizer and starts the search for the appropriate work operation through the technological database by comparing the original data from the model with the recommended data for the available tools stored in the production system [24]. The architecture of this system is shown in Fig 11.

This architecture can only collaborate with the Software applications that support boundary representation method (B-rep). Other Software applications with different data structure and mechanism for CAD cannot collaborate in this system. The architecture cannot enable different CAD/CAM application software to collaborate with each other. The architecture does not support data integration based on STEP standard. The new Software applications cannot easily join the system for collaborative CAX activities.

"**Three-tier architecture for Digital Manufacturing**" is the architecture proposed for enabling Product data management through digital manufacturing [25]. The architecture of this system is shown in Fig 12.

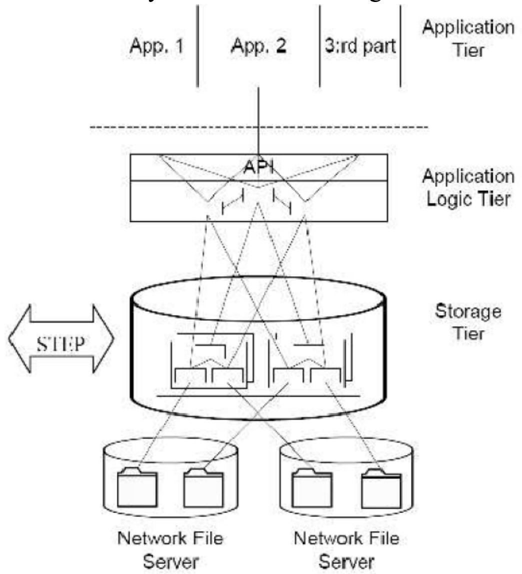

Fig 12: Three-tier architecture for Digital Manufacturing [25].

CAD-systems and other applications are in the application tier while the meta-database is in the application logic tier. The network file servers are operating in the storage tier [25]. The architecture cannot enable CAM software application and CNC devices to collaborate in is its platform.

"**VIVACE – EDM architecture**" is the architecture that was used during the VIVACE project (Value Improvement through a Virtual Aeronautical Collaborative Enterprise) [26]. The architecture of this system is shown in Fig 13. The ambition of the VIVACE EDM Framework is to manage a broader set of technical objects such as requirements, product information and simulation information, and links between these various types of technical objects [27].

Using the STEP standard enables the VIVACE to support the integration of data; however, the architecture cannot accept the software application with other data structure. The system lakes for flexibility to enable different CAD/CAM software applications. The architecture has not mechanism to manage the collaboration among software applications.

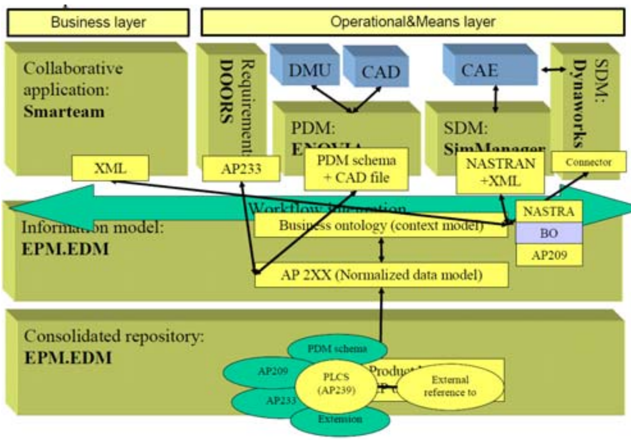

Fig 13 : Architecture exploited in VIVACE–EDM [26]

"**Web Based Collaborative Product Development System using STEP/ XML / X3D**" is the architecture developed with emphasize on Mechanical Design [28]. The architecture of this system is shown in Fig 14. CPDS (Collaborative Product Development System) is developed based on three-tier client– server architecture and on Open Sources technologies [28]. The architecture has an integrated data structure for CAD activities but do not support collaborative process planning and CNC machining. The Software applications with different data structure other than STEP cannot join the system for collaborative work. Although the system supports the distributed CAD activities, it cannot ensure the security for product data modification. New Software applications cannot easily join the system for collaborative works.

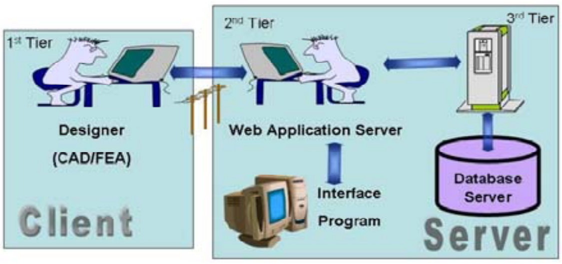

Fig 14 : Three tier architecture of CPDS [28]

"**Integrated CAD/CAPP/CAM/CNC**" is the architecture developed with the paradigm of omitting data conversion between different CAD/CAM applications [29]. The architecture focuses on STEP standards to support data exchange between CAD systems as well as facilitate data flow between CAD, CAPP, CAM, and CNC systems. The architecture of this system is shown in Fig 15. The use of STEP data structure in CAD/CAM/CAPP/CNC machining ensures the data integration based on STEP standard.

The paradigm for omitting data conversion between CAD/CAM systems and application cannot be achieved easily. The application and devices working in manufacturing areas use their own data structure. The architecture cannot support the CAD/CAM/CNC devices with data structure other that STEP. This makes the architecture inflexible for accepting the new Software applications and devices. The data security between Software applications and devices is not ensured while data transactions.

III. The Proposed Collaborative CAD/CAM Information System Architecture

The structure of the proposed collaborative CAD/CAM architecture is designed in such a way to support:

1) Integration

It considers the different aspects of an integrated information system. It is designed to enable CAD/CAM application software to use the product data. The architecture has been structured so that CAD/CAM application software can collaborate with each others. One way to make sure that CAD/CAM procedures are processed and scheduled on time is to employ a distributed agent system that repeatedly and regularly inform the current status of all elements associated with the processes. The agents must be smart, diligent, agile, and easily defined. By utilizing these agents in the manufacturing processes, the most of difficult and complex problems such as none integrated information and collaboration can quickly be solved [30]. To achieve a higher collaborative performance three layers have been designed. These layers enable CAD/CAM application software in different CAD/CAM discipline to work collaboratively.

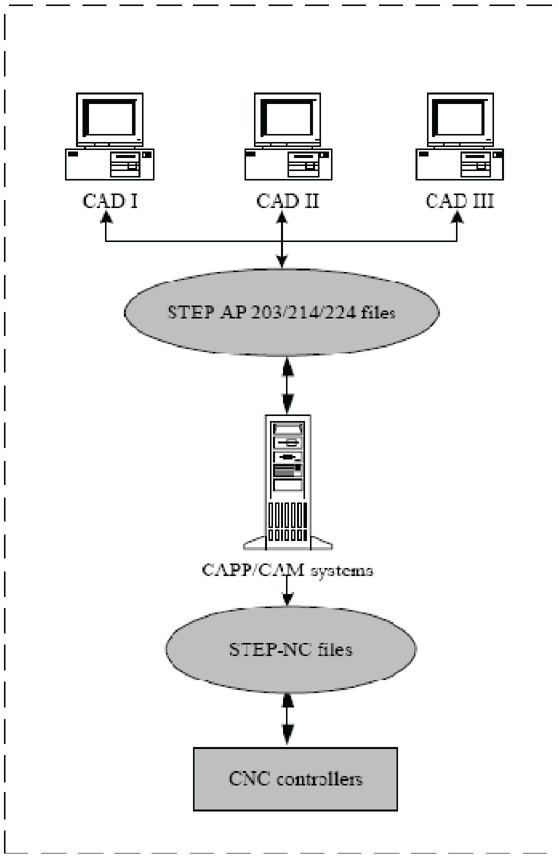

Fig 15 : Integrated CAD/CAPP/CAM/CNC [29]

2) Flexibility in data structure

The proposed architecture is able to support and transact based on STEP data standard (ISO 10303). Considering that the most of CAD/CAM application software don't support this standard for data exchange, the proposed architecture layers convert the STEP based data to different CAD/CAM data models. Vice versa the layers convert the different CAD/CAM data model to STEP data structure. The architecture depicted in Fig 16 and Fig 17.

There are three main areas in this architecture, they are:

Data Base: It saves and restores product data. The data

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storage consists of a data model structure based on the ISO 10303(STEP). The other layers send and receive information to/from it. This layer is called the data access layers. The security of data and its integration are handled in this layer.

Operations, Control and monitoring: It is the major area of the architecture. It is the core of the system which receives the product data from the Data base; it converts and delivers the data to the user interface area and vice versa.

The core of this area is called the Facade layer, this layer is the brain of this architecture. It acts as a translator, checker, synchronizer, and manager of the systems operations.

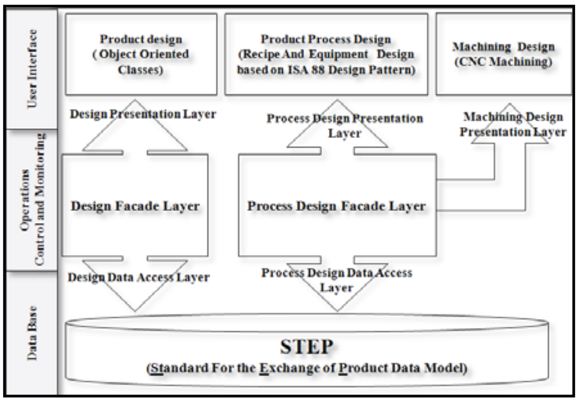

Fig 16. The Overall architecture of the system and its areas

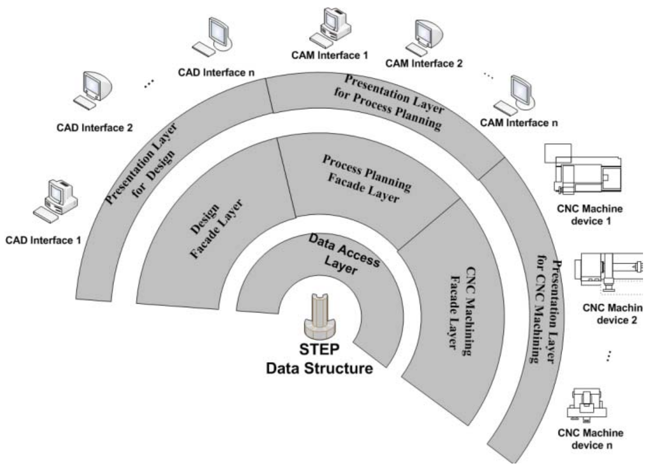

Fig 17. The architecture Layers

As the gap between CAD/CAM data structure format and STEP data structure gets more the process of translation, checking, synchronization, and management of the systems operations gets more complicated and time consuming.

Interface: It enables the different CAD/CAM application software to collaborate in integrated data Structure. They collaboratively work with each other based on their own data structure.

The Architecture of integrated information system enables the enterprises to use both a unit database repository and a discrete data base repository structure shown in Fig 18 based on their condition and constrains that exists for the enterprise.

The database of the product data model is integrated based on STEP standard. STEP standard has application protocols. The structure of product data (form its design information and data related to its production process data) is organized within this application protocols. The application protocol satisfies the integrity of product data [31]. Considering the processes for design, process planning and CNC machining, the proposed architecture uses the following Application protocols parts:

1) Part 203: configuration controlled design
2) Part 221: functional data and schematic representation for process plans
3) Part 224: mechanical product definition for process planning
4) Part 231: Process engineering data
5) Part 235: material information for products
6) Part 238: integrated CNC machining
7) Part 239: product life cycle support
8) Part 240: Process planning

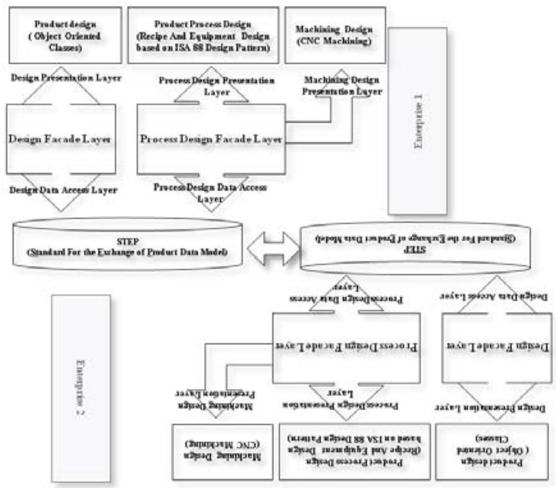

Fig 18. Integrated Information system structure for Discrete SCM enterprises

This is important to consider that UML (Unified Modeling Language) and its analytical capability is a powerful tool to construct data structure based on STEP data model. The ISO STEP committee (TC184/SC4) is also developing another standard, ISO 10303-25, EXPRESS to OMG XMI binding [32], [33] (also known as Part 25), for transforming EXPRESS schemas into UML models. This will enable developers to use their familiar UML tools to see the contents of STEP (EXPRESS) schemas and eventually to specify relationships between STEP information models and the other UML models that they use [31]. This helps the enterprises to construct the STEP data model using powerful tools like UML. Proceeding, the article describes the proposed architecture layers and their functionality.

A. *Data access Layer*

The data access layer sends and receives the product data in order to store it in data base area. This layer manages the security of CAD/CAM application software where the product data is modified. This will insure the product data security when CAD/CAM application software collaborate with each other. It helps enterprises in product development processes. This feature is essential where CAD/CAM users are distributed.

This layer checks the data integration based on STEP standard. The different stored procedures that are needed due to the program structure can work in this layer for receiving and sending the product data.

B. Facade Layer

The façade layer is the core and the most important part of this architecture. It is the brain of the architecture. The responsibilities of this layer are:

It receives the product data and information from the data access layer in the format of STEP data model. It prepares the product data to be delivered to the presentation layer. If the data is concerned with the product design the façade layer firstly uses the defined collaborative design rules and secondly it converts this data to client CAD data structure and delivers it to the presentation layer. If the data and information received from the data access layer concerns with product process planning it runs the collaborative process planning rules to convert product data from AP 224/214 data structure to CAM presentation layer. On the other hand the façade layer converts the AP 238 data model to CNC machining codes.

This layer connects the presentation layer to data access layer, this enables the data integration for database based on STEP standard while supporting different CAD/CAM data structures.

C. Presentation layer

This layer prepares the data and information for CAD/CAM software. This layer supports different CAD/CAM software collaborates with the system.

As the CAD/CAM data structure changes, the system has the capability to support the new data structure without major changes in façade layer or other layers.

For covering integrated product development, the architecture is able to communicate with three kinds of CAD/CAM application software based on standard data structure:

Product design: The proposed architecture supports the application protocols Part 203. This enables the proposed architecture to support CAD application programs. The ability of current mechanical CAD system in representing design for part, assembly and drafting/drawing is well established [34], [35]. This data structure can support most CAD disciplines.

Product process planning: The proposed architecture supports the application protocols, Part 221, Part 224, Part 231, and Part 240. This enables the proposed architecture to support CAM application programs.

CNC Machining G-codes: the application protocol Part 238 has been used in this data structure model. This application protocol is related to the products CNC machining information.

Table 1: Comparison of Proposed architecture with current architectures

Architecture	Supporting Flexible CAD application software	Supporting Flexible CAM application software	The security of information flows	Supporting distributed CAD/CAM application software	Easy Join of new CAD/CAM application software	Integration of data structure
Multi-Agent System for Computer Aided Process Planning (MASCAPP)[13]	NO	NO	YES	NO	YES	NO
STEP based Engineering Data Management (EDM) system [4]	YES	YES	NO	YES	NO	YES
STEP-compliant collaborative manufacturing model [13]	NO	NO	YES	YES	YES	NO
A STEP-based manufacturing information system [19]	YES	YES	NO	NO	NO	NO
framework for steel bridge information management [20]	YES	YES	NO	NO	YES	NO
Intelligent agent System architecture [21]	NO	NO	NO	YES	NO	NO
Prototype wire EDM system Architecture [22]	NO	NO	NO	NO	NO	YES
CAE system architecture for support multiple viewpoints [3]	YES	YES	NO	NO	YES	NO
Incremental Simulation Modeling for Internet Collaborative Design architecture [23]	NO	NO	NO	YES	YES	NO
Intelligent CAD/CAM system [24]	NO	NO	NO	NO	NO	NO
Three-tier architecture for Digital Manufacturing [25]	YES	NO	NO	NO	YES	NO
VIVACE – EDM architecture [26]	YES	YES	NO	NO	YES	NO
Web Based Collaborative Product Development System using STEP/ XML / X3D [28]	NO	NO	NO	YES	YES	NO
Integrated CAD/CAPP/CAM/CNC [29]	NO	NO	NO	NO	YES	NO
The Proposed collaborative CAD/CAM Information system Architecture	YES	YES	YES	YES	YES	YES

IV. CONCLUSIONS

Table 1 compares the current and proposed interoperable/integrated CAD/CAM architecture based on interoperability and integration indexes. The current architectures are not flexible enough to work with new CAD/CAM software systems in a collaborative product development. Some of them work only with a specified data structure format. New enterprises involved in product design and Product Process planning demand interoperable/integrated CAD/CAM architectures that connect them seamlessly and enable them to exchange product data easily. The proposed interoperable/integrated CAD/CAM architecture supports collaborative product development in different enterprises. It also supports the security of data. The architecture is comprised of different layers. These layers enable different CAD/CAM application programs to work collaboratively in an integrated environment while using their own product data structure. The layers interchange the product data within CAD/CAM application software. Having considered above features the CAD/CAM software systems will work collaboratively for product development. The layers manage and store the product data based on STEP standard. The proposed interoperable/integrated CAD/CAM architecture has a flexible capability to integrate CAD/CAPP/CAM software systems and CNC devices. In further work authors will consider the capability of proposed architecture.

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