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Research Article

Developing a STEP-Compliant Multiagent on an Interoperable and Integrated CAD/CAM Platform

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Practical implementation of a STEP-based architecture to provide a fully integrated and interoperable platform of data exchange has always been an intriguing issue. A variety of CAD/CAM environments are struggling to embed and support STEP standard and its protocols in order to seamlessly operate within global data exchange. However, apparent paucity of efficient and reliable structure for data communication, manipulation, and restoration has remarkably hindered the desired progress. In this paper, taking these shortcomings into account, a practical architecture is introduced and STEP-based agents are implemented and installed on the platform. Moreover, feature recognition, interaction, and machining precedence as crucial issues of CAD/CAM research have been considered in developing the interoperable platform. Seamless integration and interaction of CAD/CAM modules are provided in the proposed system. The prototype is finally verified and discussed through a case study.

1. Introduction

Since more than a decade ago, interoperability and integration in CAD/CAM environment, have been notably investigated. Quick and faultless data communications throughout product and process development are becoming imperative day to day. This is mainly due to disseminating vendors and complex-structured organizations of design and manufacturing. Needless to say, promising progress in developing neutral standards and their pertinent extensions within recent years are construed as driving wheels for the integration vehicle. Neutral standards do not ordinarily depend on any proprietary application or platform. They are mostly easy to be dealt with, manipulated, and interpreted while having a potent structure to entirely capture product-lifecycle data. Loosely claiming, future generations of product data management (PDM) must be neutral format-compliant in order to fully achieve interoperability [1, 2]. STEP (the Standard for Exchange of Product data) has played an underlying role in implementation of CAD/CAM integrated systems [3]. Taking STEP's numerous advantages into account and relying on its unique capabilities, this research proposes an integrated CAD/CAM architecture to provide the organizations with an interoperable platform of data exchange. STEP-compliant agents are then installed on the platform and a system which benefits the merits of the developed platforms is designed and implemented. Feature recognition, interaction, and machining precedence are some crucial issues that are particularly dealt with through developing the proposed prototype. This achievement assures integration, interoperability, and data management and entails design, process planning, and manufacturing up to CNC machining.

In the following sections, the relevant attempts to utilize STEP in CAD/CAM integration are discussed and a proper platform is introduced. Conforming CAD/CAM agents are then defined and a prototype is implemented to represent the realized integration and interoperability. Eventually, this achievement is validated by design and test of a case study.

2. STEP-Based Interoperable and Integrated CAD/CAM System

Software solutions that facilitate distributed product design and manufacturing are becoming more important in product development processes [4, 5]. Different solutions and applications that have been proposed based on these frameworks include different CAD/CAM software packages. Technologies developed for CAD/CAM software packages are improved and used through their own application domains named as automation islands [6, 7]. Therefore, the application of these software tools in different enterprises will cause trouble when there is need to exchange product data among engineers and designers who are geographically dispersed.

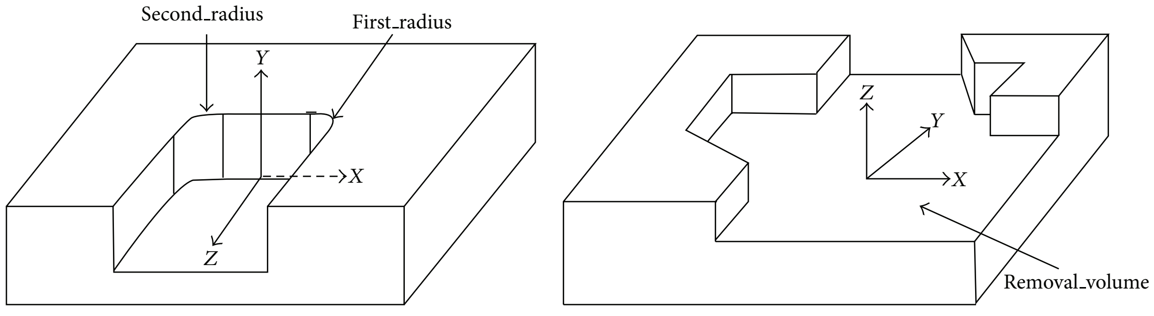
In recent years, different developed solutions have been introduced to ensure the integrity and interoperability among different CAD/CAM systems. Also neutral data format for exchanging the product data has been widely utilized [8–10]. Some of these formats are recognized as STEP, IGES, PARASOLID, STL, and ACIS. However, among all, STEP standard and its protocols, firstly introduced in 1994, found broad interest in research and practice [11–14]. Unlike the other formats, STEP is able to encapsulate the entire product data throughout the lifecycle into a well-organized structure, independent of any particular device or application [15]. Particularly, to exchange CAx data including features information, design details, and process planning data, STEP has been extensively addressed by many authors. Xu in 2005 [16] and 2009 [7] and Nassehi et al. in 2006 [17] suggested information systems with the ability for product data integration based on the STEP standard. However, these systems generally lacked tools for enabling interoperability for product data exchange between different CAx software packages. In computer-aided design, STEP application protocols, AP203 and 214, provide all the information required to represent the part design specifications. AP 224 which entails mechanical feature definition has been utilized to develop some process plan systems [18]. Among recent researches, the authors discussed the significant characteristics for a desired STEP-based platform capable of supporting interoperability and collaboration management of CAD/CAM agents [19]. They propose INFELT STEP, an interoperable and collaborative platform. An all-out investigation over the specification and capabilities of this platform along with its key advantages over the existing counterparts has also been carried out [20]. This way, INFELT STEP is considered as the platform to support integrity and interoperability among CAD/CAPP/CAM agents. This outcome copes with the drawbacks of the previous platforms and obviates the existing obstructions in realizing seamless integration. A variety of STEP-based design and manufacturing agents have been addressed, in all of which the core part is feature. Although definition of STEP feature has indisputable benefits toward integrating CAD and CAM, design, recognition, interaction, and machining precedence of features remained substantial issues to be handled.

3. STEP Features, Design, Recognition, Interaction, and Precedence

Across all domains of discourse, the terminology feature has found numerous definitions. However, in the CAD/CAM literature, features are principally considered as types of shape (such as a pocket, slot, or hole) associated with design, process plan, or manufacturing of a piece part [21]. Since features serve as automatic and intelligent interpreter to link CAD with CAM and are key elements to enable integration of design and manufacturing, they must be clearly defined, uniquely interpreted, and efficiently utilized [22]. Feature recognition is the crucial task of conveying conventional CAD models in terms of pure geometry and topology to high-level and domain-specific machining features. In spite of commercial implementation of feature-based design in CAD applications, mapping design to manufacturing features still fetters integrating of the two domains. On the other hand, in arbitrary design, recognising even primitive features from the low-level information of vertices, edges, faces and so on, remain a computationally time-consuming and expensive duty [21]. If the geometric and topologic specifications are produced through CAD software with low-level entities, the process of detecting STEP features requires a feature recognition agent. The process may search throughout the huge B-Rep data-file in order to elicit the entities of STEP and identify the attributes shown in Figure 1(a). More detail could be obtained in the literature [13, 23, 24].

However, if the design process starts with a feature-based modeller (like what occurs in CATIA/ProE feature-based CADs), mapping them into manufacturing and STEP-compliant features is another momentous and also strenuous task. To overcome these troubles, STEP feature-based modeller must be built by which the designer can easily drag and drop the predefined features and make the 3D model.

Benefited from its generic nature, computer-interpretable format, and consistent data implementations across multiple applications, STEP standard provides an enriched data model to define the features and their corresponding details [25]. Each feature is implicitly or explicitly defined through some geometrical attributes. In STEP AP203, which captures the data of configuration of controlled 3D designs, the explicit geometry using boundary representation is provided. This B-rep model includes all the essential inputs to recognize the design features. More specifically, AP 224 denotes implicit information of machining features along with their initial attachment of dimensional and geometric tolerances. In addition to precise delineation of feature semantics in STEP, access to set of integrated resources permits application protocols to interpret the resources associated with product requirements. This way, enriching feature's attributes throughout product lifecycle is remarkably straightforward. Most of CAD solutions currently allow restoration of 3D design in 10303-203 standard format while very few give possibility of saving it as 10303-224 [13, 26]. Dereli and Filiz applied some restrictions to feature-based design in order to automatically recognise the STEP features from their originally B-Rep structure [23]. Aiming to achieve a shop floor STEP-compliant architecture, a feature recognition prototype, so-called SFPS, has been developed in Pohang University of the Republic of Korea [27–29]. The input is given by AP203 and the output is the feature list in terms of AP238 format which has by far the most compatibility with ISO 14649, STEP-NC ARM model. The outcomes might be part 21 or 28 of implementation method of ISO 10303 depending on either offline or online data communication (Figure 2).



(a)

(b)

Figure 1: (a) a flat slot end type defined in AP224; (b) a combined feature defined in AP224.

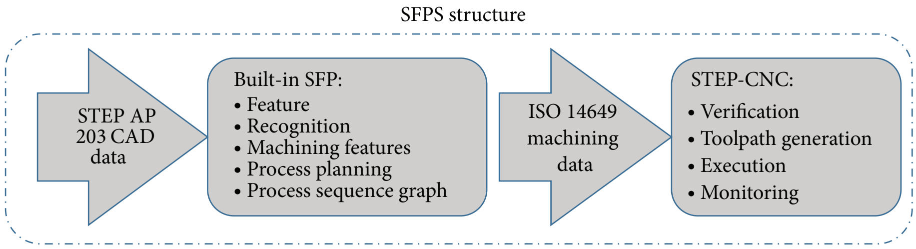


Figure 2: STEP-Compliant Feature Recognition agent.

Feature recognition process becomes more intriguing due to possible geometric interaction of features. Volumetric or surface collisions between features' geometry have affecting consequences on their recognition, interpretation, and machining sequence [30, 31]. Feature interaction and multiple interpretations are not addressed in STEP data model. To simplify the representation of machining features with the same depth of bottom conditions, some combinational features are introduced by STEP (Figure 1(b)). An instance is interaction of a slot and a pocket with identical depression to the top surface which is described as a single closed profile.

Discourse of STEP features interaction has been meticulously dealt with by Mokhtar et al. [32]. They successfully implemented a prototype to detect and visualise feature interactions of both volumetric and surface types out of STEP-NC (ISO14649 version) [33].

Process planning, as a significant task in product development lifecycle, entails feature recognition and interpretation and then their machining precedence and sequence. Once the removable volumes are recognized and defined in terms of machining features, the momentous task is to allocate their priority to cut. Feature precedence, which is considered as a prerequisite to final machining sequence, denotes for some preferences or obligations to define which feature(s) to be cut before/after the other one(s). This becomes more complicated when features geometrically or technologically interact [32]. Although precedence of intersecting features is widely discussed in the literature, a sparse number of researches apply it in neutral data models.

The STEP data model (i.e., AP 238) allows machining operations and the cutting tools to be defined for every feature resulting in a new entity called *Workingstep* (ISO 2003d; ISO 2004). *Machining_workingsteps* represent the machining process for a specified area on the work piece, for example, a feature. Taking AP 203/214 as the input, Arivazhagan et al. subtract the rough-machined part from the final part to identify the finish-cut machinable volumes in prismatic parts [34]. Nevertheless, the outcome could not be restored in compliance with STEP standard and intersecting features are not discussed. In Rameshbabu and Shunmugam's contribution, this method merges with face adjacency graph to recognize manufacturing features from STEP AP-203 format [35]. However, this achievement suffers from lack of interoperability with downstream STEP-compliant functions.

When two STEP features interact, the type of interaction could be restored in the data model and based on the appended information, and a precedence is allocated to its belonging working steps. This way, the working steps are ordered due to some precedence rules that can be applied to machining features. Precedence rules have been comprehensively discussed and applied in a prototype developed by Mokhtar and Xu [33]. The so-called hard and soft precedence constraints for interacting features and roughing and finishing operations are also dealt with. Each STEP feature may encompass more than one working step due to its need for the number of cuts (machining passes) to reach the final shape and tolerance. The central advantage of their proposed system is relying on a STEP-in/STEP-out architecture which permits integration with upstream/downstream activities (Figure 3). The result is generated in a STEP-NC file having a close to optimum list of operations sequence.

4. Proposed Prototype: The INFELT-STEP-NC

INFELT STEP is an integrated, three-layered, and interoperable platform for collaborative CAD/CAPP/CAM/CNC

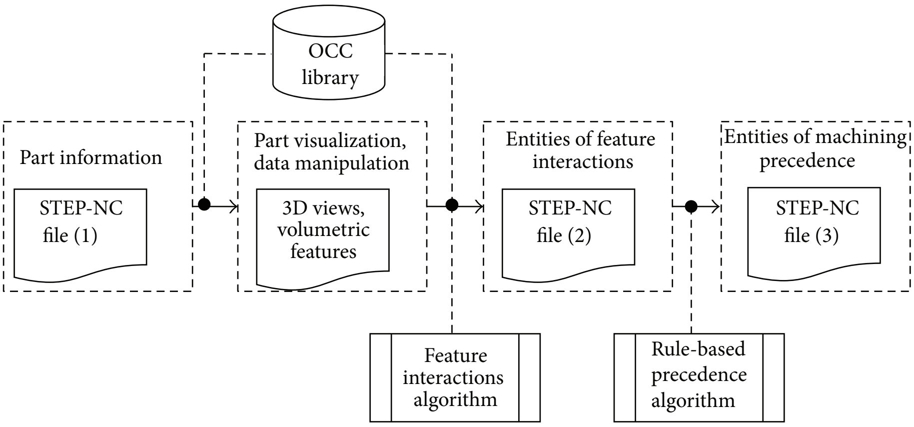


FIGURE 3: STEP-Compliant process planning agent.

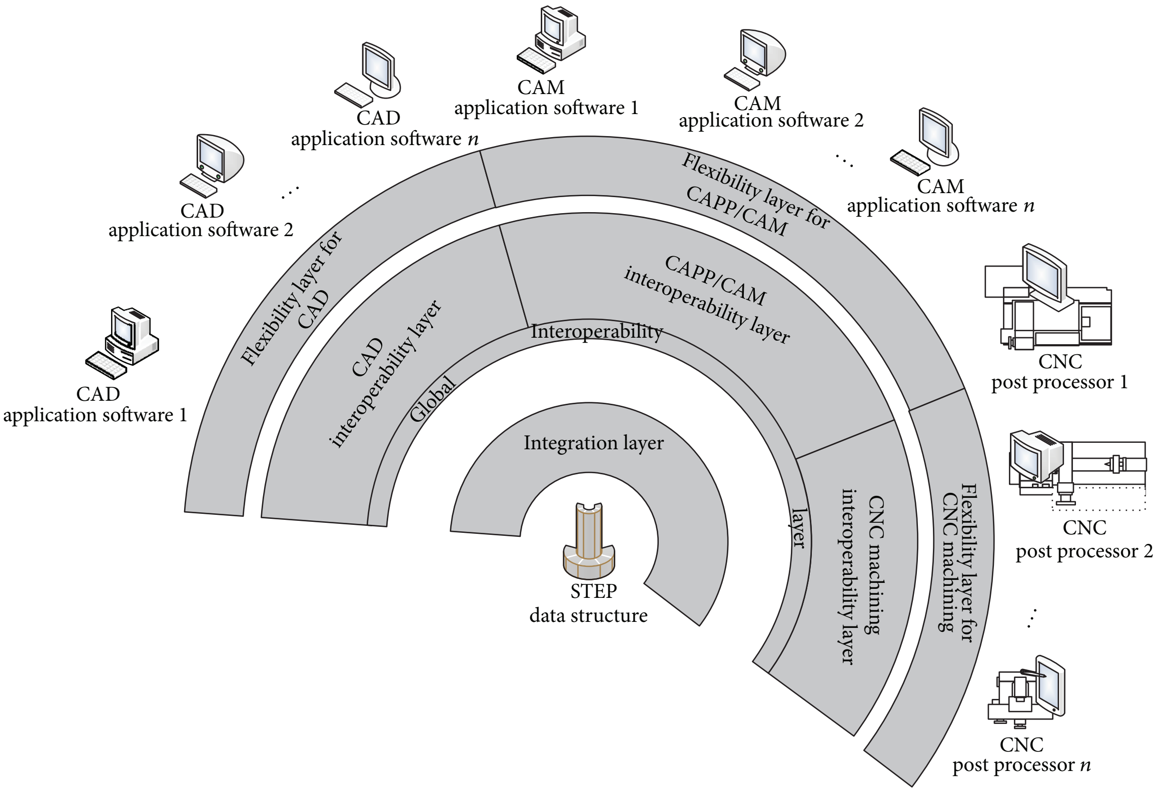


FIGURE 4: INFELT STEP structure [20].

machining systems based on the STEP standard [19]. The INFELT STEP has functionalities to work with different distributed CAD/CAM software packages [36] and CNC post processors. The layered structure of the INFELT STEP platform is shown in Figure 4. INFELT STEP consisting of procedures enables different CAx software packages and CNC post processors to join the platform for interoperability. These distributed devices and applications might use their own defined data structure. Moreover, the platform also has procedures to ensure CAD/CAM product data integration.

A prototype which benefits the INFELT three-layered architecture and relies on STEP-in/STEP-out processor is introduced and implemented in this research. The INFELT supports the different activity-based agents to collaborate with each other based on their own data structure and integrate the design and manufacturing data based on the STEP standard. The so-called INFELT-STEP-NC has integrated resource of STEP applications and the database to ensure data collaboration while providing the operator with the chance to switch back and forth between different data models like STEP and IGES.

In the proposed system, design activity can be performed in either feature-based or arbitrarily in a CAD environment. Design on the basis of features is possible using graphical

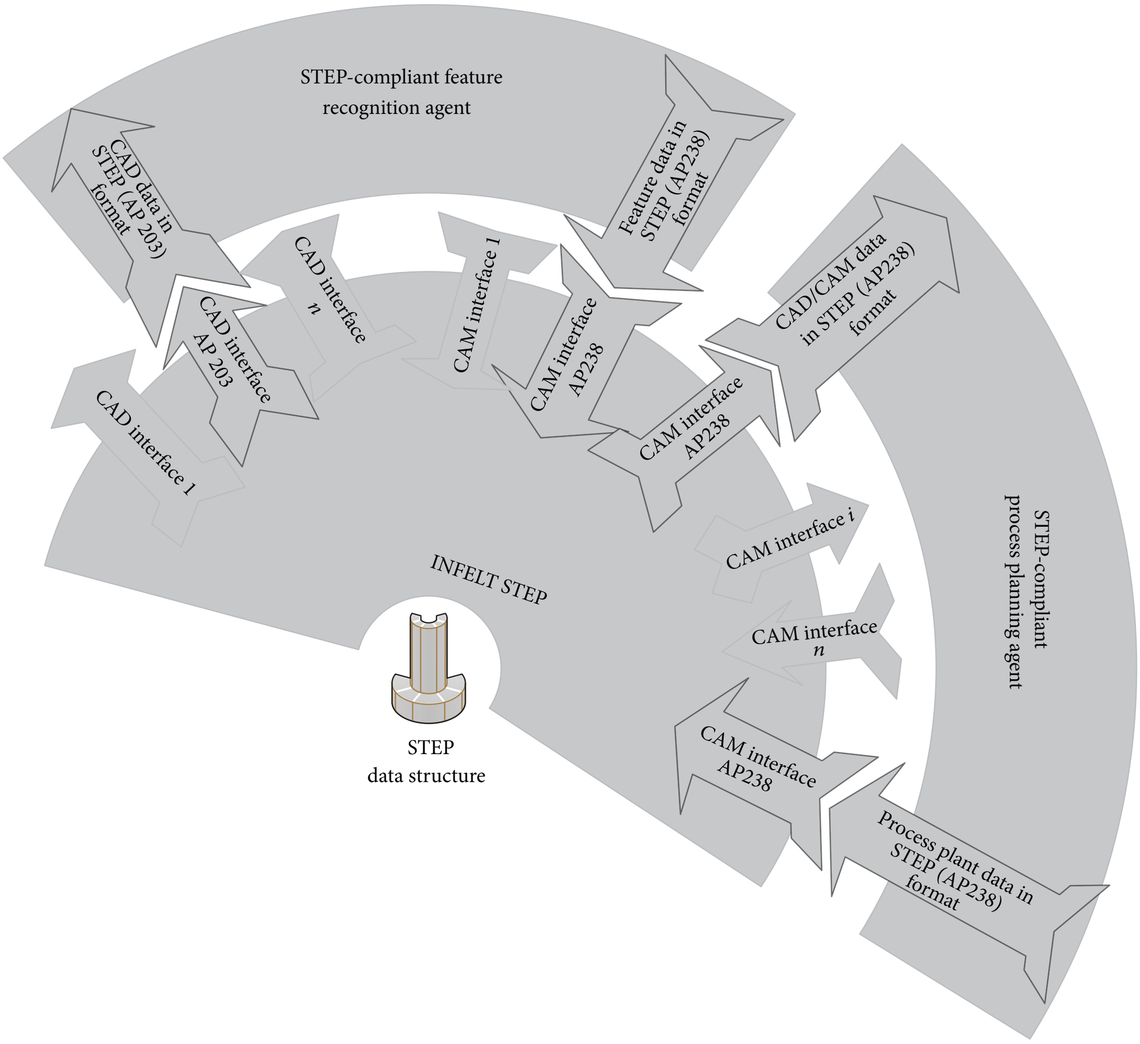


Figure 5: Feature recognition and process planning agents collaborate in INFELT STEP architecture.

instance which provides the operator with a GUI. Milling schema and machining schema elicited from ISO 14649 data model parts 10, 11, and 111 have been combined and presented in graphical instance. Therefore, the designer automatically generates STEP features while drags and drops machining features from the prepared list. Attribute values such as depth and profile parameters for a specific 2.5D feature may be appended later on or during design process. Design agent is also able to restore the CAD output in terms of AP203 which mainly contains B-Rep information to represent the geometry and topology of the part. Feature recognition agent, which is responsible for extracting the STEP feature lists from B-Rep data, is SFP package. This package will be utilised if the design process is earlier performed using a non-feature-based designer such as AutoCAD. The output will be maintained in the format of ISO10303-238. The next agent is process planning that ensures features validity, resolves feature interactions, and assigns a rough operation sequence. The processed information is acquired in a STEP-NC file.

Figure 5 shows how different modules such as design, feature recognition, and process planning are installed on the framework.

5. Case Studies and Discussion

A part with nine machining features and twelve pairs of interactions which incorporates a step, two slots, two open and closed pockets, three holes, and a chamfer is considered as the case study (Figure 6). The authors developed a platform to conduct the case study. The platform is developed by means of Visual Studio 2010 and SQL server 2008. The agents were created based on the object oriented concepts. The authors implemented AP 238's related integrated resources (IRs) data model in SQL server 2008 database. Moreover, the authors defined mapping rules for CAD data formats like .DXF. The program uses these rules to map the geometric data to STEP standard data structure and vice versa, from the STEP standard data structures to .DXF data structures. The program benefits from a feature recognition module to exchange the feature data based on the STEP standard data structures. The authors used XML technology for data exchange. The overall architecture of the system was a three-layered one. The part is designed by means of AutoCAD software package. The CAD data are delivered to the flexibility layer of INFELT STEP platform. The outputs are

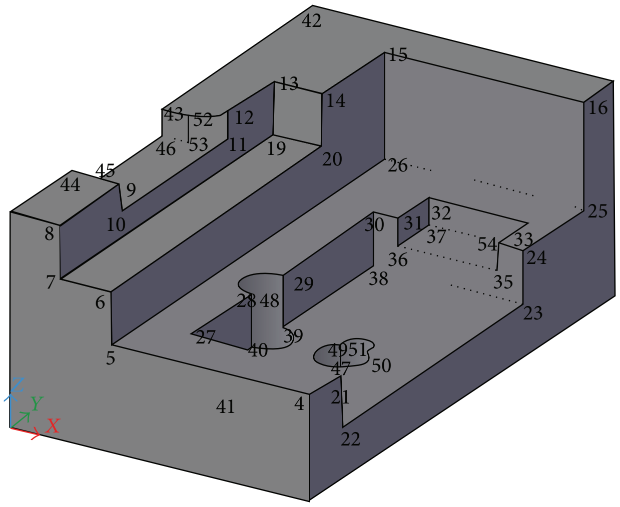


Figure 6: The case study part.

based on DXF format. The DXF interface in flexibility layer receives the CAD data and presents it to the interoperability layer (supplementary Appendix A in Supplementary Material available online at http://dx.doi.org/10.1155/2013/974759). The interoperability layer then transforms the DXF data to STEP-based CAD data which is compliant with application protocol 203 (supplementary Appendix B). The features have been recognized employing the STEP-Compliant Feature Recognition agent introduced earlier and displayed in Figure 2. This agent extracts the features in the form machining features compatible with the content of ISO 14649. The output is listed in supplementary Appendix C.

The CAD data are delivered to the integration layer to be restored based on STEP standard integrated resources. The feature recognition agent submits its request to INFELT STEP to receive the CAD data based on STEP application protocol 203. The CAD data which are retrieved from integration layer and the interoperability layer drive the CAD specification away to the STEP-based interface installed on the flexibility layer based on STEP data structure. The feature recognition agent receives the CAD data, generates the process planning features, and delivers the feature information based on the STEP standard to the INFELT STEP platform (Appendix C). The AP238 interfaces in the flexibility layer take the STEP based feature data and send them to the interoperability layer in XML format. The interoperability layer passes the feature data to the integration layer in order to be maintained associating with the application protocol 238 (Appendix D). The integration layer receives the feature data and stores them based on related integrated resources. The process planning agent sends its request for retrieving the part data based on STEP standard application protocol 238. The interoperability layer retrieves the CAD and feature data based on STEP standard. These data are delivered to the flexibility layer in XML format based on AP238 data structure. The process planning agent receives the CAD and feature data and starts the process planning activity. This process planning agent that is a STEP-in/STEP-out application generates the interaction and machining precedence. The precedence information as described below is produced and appended to the feature data. The outcome is based on STEP-NC data structure and is delivered to the flexibility layer to be stored. The flexibility layer delivers the precedence and process planning data to the interoperability layer in XML format. The CAD/CAPP/CAM data are mapped based on application protocol 238 to STEP-based integrated resources and delivered to the integration layer to be stored. The integration layer receives the CAD/CAPP/CAM data and stores them based on STEP integrated resources. This product data exchange between agents is shown in Figure 7.

Based on the interaction type between these features, the following machining precedence are established. *Hard Precedence:* roughing operations for both pockets and all three holes are to be performed after rough-milling the step; operations for making hole F^6 should precede the machining of the open pocket; rounding off the edge (F^0) should not be performed before roughing and finishing of its two interacting slots. *Soft Precedence:* roughing of the open pocket is best carried out before that of the closed pocket; the bigger slot is best rough-milled before the smaller one; both drilling and reaming operations for the smaller hole (F^8) precede drilling and reaming of the bigger one (F^7); the finishing operations for these two holes can be procrastinated until the open pocket is finished; both pockets are nested in the step. Therefore, they should be rough-machined before finishing the step and, due to the interactions between adjacent features such as the slots, pockets, and step, each one of these features should have its finishing operation carried out after the roughing operation of its interacting feature. While generating this information is the significant part of process planning, maintaining it in terms of STEP semantics is extremely helpful for further tasks. The working steps of STEP-NC file are ordered taking the aforementioned precedence rules into account. However, work piece specifications, cutting tool geometry, and cutting parameters are to be specified manually by the expert.

6. Conclusions

An interoperable platform was introduced to integrate the CAD/CAM/CAPP information. The platform utilizes the neutral data model of STEP standard in order to read, restore, and retrieve the data associated with product design and process planning. Two agents of feature recognition and process planning were installed on the platform to demonstrate its current and potential capabilities in developing a fully integrated CAD/CAM environment. The implemented prototype, the so-called INFELT-STEP-NC, starts with a CAD file and restores it through STEP integrated resource model. Then, the recognition agent extracts the feature information and the process planning agent deals with interaction and precedence of machining features. All these fundamental tasks are performed via an integrated and STEP-compliant architecture. For further research, allocation of machining parameters might be carried out using an automatic micro-process planning agent(s) using either rule-based system or optimization algorithms such as the STEP-compliant feed-rate optimizer recently developed by Ridwan et al. at the

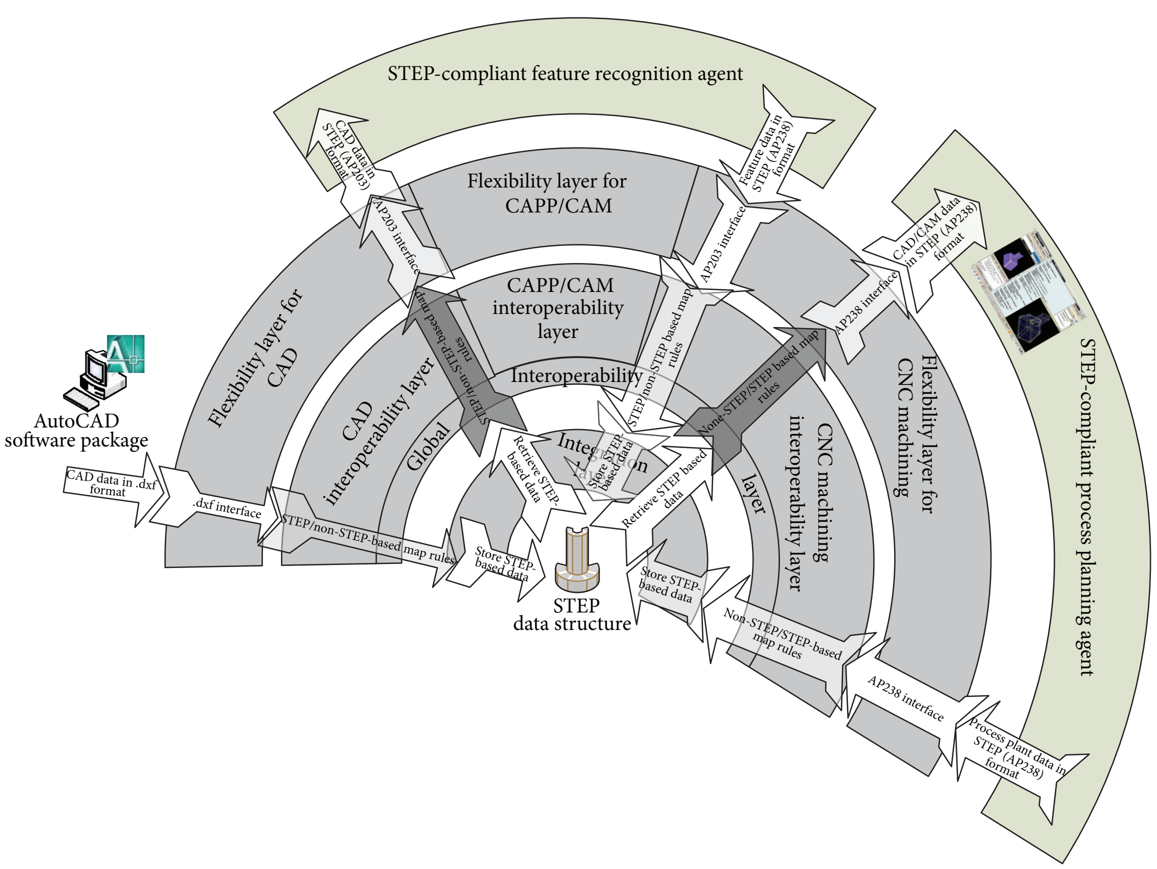


Figure 7: The case study part data exchange between agents and INFELT STEP platform.

University of Auckland [37]. Moreover, an intelligent STEP-CNC (or G-code convertor) agent which enables machining the CAM file on a CNC-mill might be developed and installed on the platform to read and convert the STEP-NC file and generate tool trajectories. In succinct, while having reliable structure and robust data management, the current system pointed out a long but bright way ahead in order to achieve integration, interoperability, and collaboration in CAD/CAM/CAPP/CNC domain.

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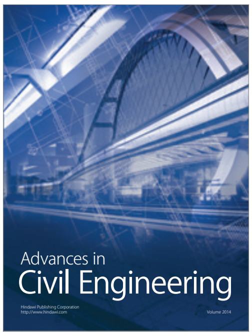
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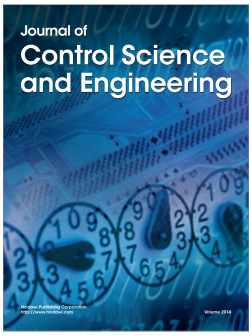
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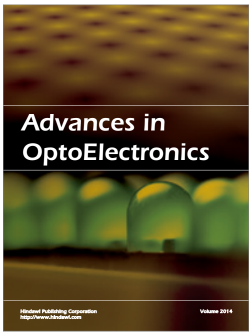
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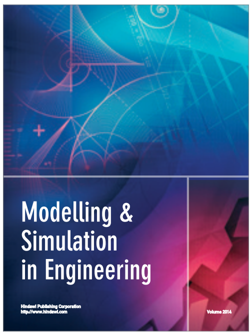
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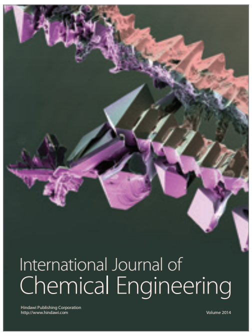
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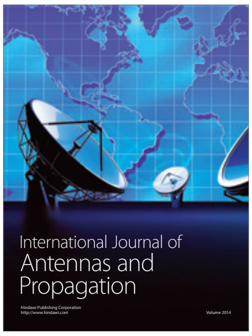
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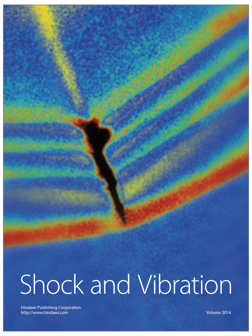
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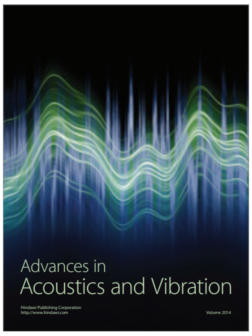
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