# Examining CAD Interoperability through the Use of Ontologies

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**ABSTRACT**

Product data interoperability in CAD systems has become one of the key areas of concern for collaboration of work and integration of product data through various phases of a product lifecycle. In this paper, we propose a framework which uses an ontology to bridge the data interoperability gap between various CAD software systems allowing these systems to interact with each other during a productǒs lifecycle. An ontology is created from the native file from a CAD system through an intermediate standard format, STEP. The ontology represents the geometric product data from the CAD file and the semantics of the product data. The ontology is converted back into a STEP file to be used by another CAD system. This could be an open source alternative to expensive proprietary software packages used for this type of data conversion.

**Keywords:** PLM, ontology, data interoperability, STEP, Protégé, OWL
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## 1 INTRODUCTION

Current product design and manufacturing projects demand for a broad range of skills and a variety of technologies to develop a product. Thus, collaboration has become very important. Organizations need to share and exchange data among several of their own branches spread across geographical boundaries and with other organizations across the globe. Outsourcing and insourcing make it even more desirable. There arises a need for a common central knowledge base of product data which can be accessed for the right information at the right time for the right person in the right time [6]. Product Lifecycle Management is a viable solution. ǲPLM systems are distributed technological information systems for archiving, administrating and providing all product or facility related information in required quality and at the right time and placeǳ [1]. It establishes a shared platform for collaboration among various stakeholders over the entire product lifecycle from conception to phase-out stage [2].

However, there exist limitations for the full-fledged deployment of product lifecycle management (PLM) systems in the field of engineering design. One source of these limitations is related to the data interoperability gap between various CAD systems used in product design. Most companies these days have different CAD systems in house and when they collaborate with other companies outside, they might have to deal with other different CAD systems. There arises a data interoperability gap due to heterogeneous data representations used by various applications. Different ways to describe the same objects and facts or the use of different encodings and conceptualizations for a domain leads to the conflicts of semantics [12]. To overcome this data inoperability issue, International Standards Organization (ISO) developed a standard, ISO10303, informally known as STEP (Standard for Exchange of Product model data). This standard aims to make the integration of systems in various phases of the product lifecycle simpler. As part of the STEP standard, several different Application Protocols (APs) are defined which pertain to one or more of the different phases in the product lifecycle and different industry domains. For example, STEP AP 203ed2 pertains to configuration controlled 3D design and STEP 240 pertains to process plans for machined products. The STEP standard uses the EXPRESS modeling language to define data models. However, the STEP standard in the EXPRESS language cannot be used to capture semantics related to the product like product information, construction history and design intent which is one of the important characteristic of an applicable PLM tool [9]. Semantics refers to the meaning or an interpretation of the meaning. Semantics are all pervasive and covers many aspects such as the interpretation and the user perspective of the data [11]. In *Ontology based exchange of Product data semantics*, Patil, Dutta & Sriram (2005) propose the use of ontologies to overcome the limitations in using the STEP standard.

An ontology formally represents knowledge as a set of concepts within a domain, and the relationships between those concepts. It can be used to reason about the entities within that domain, and may be used to describe the domain. As an ontology can be used to represent knowledge as a set of concepts and the relationship between these concepts, it can be used to represent the product data in all the various phases of a productǿs lifecycle. Therefore, an ontology could be used in the data translation process which involves translation of product data from one CAD system to another. According to Zhan, Jayaram, Kim & Zhu (2010), traditional data translation process can be improved by introducing knowledge representation and reasoning mechanisms. An ontology defined in the Web Ontology Language (OWL) can be used for knowledge representation as mentioned earlier. OWL-DL is a description logic that helps in inferring and reasoning over the ontology which represents semantic data. Therefore, both the criterion presented by Kim et al can be satisfied by using an ontology.

This paper proposes a methodology for exchange of product data including semantics within disparate CAD software systems and through the different phases of a product lifecycle.

## 2 MOTIVATION

The traditional product lifecycle model followed by most organizations today follows a sequential approach. This means that a new phase begins only after the previous phase has been finished. This is followed from conception to retirement stage. However, there might arise a need to jump between various phases. For example, a product in the development phase may need some modifications in the prototype. So, the product data needs to move back to the prototyping phase, the necessary modifications are made and then come back to the development phase. In typical data exchange environments, it takes a lot of time to convert the data represented in each of the phases into a format the other phases can interpret and eventually, costs more money. Also, information exchange between the various phases is not feasible. For example, data might be stored in the form of spreadsheets in the support phase. If the development phase requires performing data analysis, it cannot utilize data in a spreadsheet. Here too, the problem arises from heterogeneous data formats.

**ò**The potential benefits of a PLM system are hindered by the immense amount of product data and the lack of a mechanism to manage it efficiently**ó** [7]. However, by using the concept of ontologies, a single ontology can be developed which is not language specific. It can be viewed as a central database everyone can access from any phase in the product lifecycle across various CAD systems. When the ontology is accessed, there will not be a need for any additional processing to interpret and use the knowledge represented by the ontology. Also, jumping between phases becomes easier since there is no discrepancy between the data stored and manipulated in each of the phases. A core ontology also eliminates the inconsistency between data represented by various phases of the product lifecycle. In essence, semantic interoperability can be achieved along with data interoperability. Other advantages for using an ontology include decision making capabilities, consistency checking, inferencing and having a shared vocabulary for the creation of shareable and repeatable ontologies. Another important factor that supports our motivation towards this methodology is the fact that it is flexible enough to accommodate the use of any ontology. While it is not the authors**ô** goal to develop a PLM or data exchange ontology per se, it is implied that ontologies could be used to develop a **ò**recipe**ó** for exchanging CAD data based on command-level mapping between different CAD systems.

## 3 RELATED WORK

The use of the ISO standard STEP data model for data exchange and the implementation of an ontology to capture and share design knowledge in an attempt to make the collaboration easier between various systems and stakeholders using different CAD systems easier is not new. Much work has being done in this area, but our concept of implementing an ontology to represent the product data information via the STEP standard differs from previous research done on this front.

Patil, Dutta, & Sriram (2005) discussed the need for the development of architecture to support the integration of various information resources. That work emphasizes the importance of capturing the semantics of the product data information from different sources and focuses on representing knowledge in **ò**an unambiguous and computer interpretable representation**ó**. Further, a framework called Product Semantics Representation Language (PSRL) which uses the Web Ontology language (OWL) is introduced as a standard for using an ontology to represent product knowledge. However, the usage of PSRL is limited in that it cannot be used to encompass the stakeholders in all the phases of the product lifecycle.

Zhan, Jayaram, Kim & Zhu (2010) propose an ontology based approach **ò**to share knowledge related to product data in CAD/CAE applications and for integrating the design evaluation information that these applications individually provide**ó** which they termed as ontology-based adaptive design evaluation (OADE). They propose the use of a 3 layer ontology structure and this framework involves defining the source ontology from the source product data via the ontology structure. The algorithms to determine mapping of the concepts between the source and target ontology are presented, and finally, the mapping techniques are used to generate a target ontology from the source ontology. The STEP standard is not used at all in the process. The implementation of the ontology between the CAD systems PRO/E and VADE is demonstrated. Further developments on this publication are presented in a follow-up paper [15].

Zhu, Jayaram, Jayaram & Kim (2009) in their publication *Ontology-driven integration of CAD/CAE applications: Strategies and Comparisons*, discuss the need for a standard format to communicate and exchange product information between various CAD/CAE applications. The disadvantages of using a standard like STEP which include STEP operating only at the data level and adopting different application protocols (AP) for each particular industry domain are presented. They discuss the difficulty involved in developing different APs for each domain and the additional and complex work required for defining Application Integrated Constructs (AICs) to communicate between different APs. They assert that semantic information such as design intent and design history cannot be represented using STEP and state that using an ontology in a 3-tier ontology structure might be the right solution since it introduces knowledge representation and reasoning mechanisms into product engineering [15]. However, with the ongoing development of AP 203e2 and the newly-specified AP 242, the STEP standard will be able to incorpoprate semantic geometry and product manufacturing information exchange. However, it is unlikely that CAD developers will implement the full functionality. Zhu et.al. also discourage the use of STEP as a standard and conclude on using an ontology for the improvement of traditional data conversion process. An application specific ontology for each of the 3 applications used is created via Protégé. The product information created in a CAD/CAE application is extracted by means of an API. The concepts in the initial application specific ontology in Protégé are instantiated using this product data. To integrate the product data from disparate CAD/CAE applications at the semantic level, several required mapping techniques are presented. While this paper discusses the implementation of only an ontology without using the STEP standard at all, our idea is to use a combination of STEP standard and an ontology. Also, the reasons presented in this paper discouraging the implementation of STEP can be overcome by using an ontology in combination with STEP which is presented in this paper.

Zhang & Yin (2008) propose an ontology-based modeling framework to the engineering design knowledge on the Semantic web. **ò**It evolves along five consecutive layers: knowledge elicitation, product modeling, ontology modeling, knowledge reuse and knowledge application layers, with diverse knowledge assets wrapped up as ontology-based Web services to facilitate knowledge consumption, reuse and supply on the Semantic Web**ó**. The application domain selected is that of automatic assembly system design for manufacturing electronic connectors. The domain knowledge used for creating an ontology manually was obtained from interviews with domain experts. This ontology implementation differs from previous research work on ontology based knowledge representation in that it associates multidisciplinary product models with ontology models through semantic indexes and also provides a way to map high level requirements like functions [14].

Seo, Lee, Cheon & Patil (2005) suggest the development of a feature-based ontology to enhance semantic interoperability between CAD systems. The feature-based ontology is built **ò**based on the feature definition of modeling commands of CAD systems**ó**. They used the concept of a shared ontology. Solidworks and CATIA are used to create a model and the model in each of the CAD applications native format were exported in the form of script files. Since each CAD system defines the same product feature in a different way, to preserve semantics of the definitions, **ò**mappings for concepts and relation axioms have been manually defined**ó**. The script files from the CAD systems are translated into instance files which comply with their respective source ontology. Modifications can be done on these instance files via third-party commercial tools which generate commands that comply with the shared ontology. Finally, these files are translated back to the script files for each CAD application and can be accessed and modified in the CAD systems native format. This methodology complies with STEP 224 which is an API for Mechanical Product Definition for Process Planning Using Machining Features.

Matsokis & Kiritsis (2010) propose the development of an ontology for the product data and Knowledge Management Semantic Object Model (SOM). SOM was initially developed for a single product using Unified Modeling Language (UML) for a single product. This model is translated into an ontology while preserving the complete functionality of the previous UML based model and further modifications to the ontology were incorporated making it capable of storing data about multiple products on a single source and giving it higher description ability. OWL-DL and semantic web rules were used in developing the ontology. This work is a significant improvement over previous works since it uses Description Logic in an ontology which enables reasoning but it mostly focuses on building ontologies from existing models. Our work also uses the OWL-DL (Web Ontology Language-Description Logic) to enable reasoning and to detect inconsistencies in the ontology but since we are using the STEP standard as an intermediate format, an ontology can be developed for any product data from multiple CAD applications.

The concept of a new design support environment based on multiple-views product modeling using STEP has been proposed by Song, Eynard, Roucoules, Lafon & Charles (2000). They state the two most prevalent difficulties for most commercial CAD/CAM systems to support concurrent engineering are that most CAD systems are based on geometric approach which is no longer sufficient to support the product design, and that the models of thee computer systems are heterogeneous since they have been developed separately. Their approach enables each development phase to focus on the information that is relevant to that phase and integrates information from all the phases and allows for collaboration between designers. STEP is used as an interface between CAx systems and the multiple-views product modeler. The use of an ontology in our proposed methodology is analogous to the use of the multiple-view product modeler in this approach. Previous research focused on development of an ontology from a CAD file for a single model or an individual application domain. This increases the overhead because the same model created in different CAD systems could have different ontological representations. The same goes for individual APIôs. To overcome this, our research uses the STEP standard as an intermediate format for the development of ontologies. Since STEP is an international standard, almost all the CAD systems can import and export STEP files. This will enable the generation of shareable and repeatable ontologies. Using an ontology can also help in standardization of the product data representation since it is a shared vocabulary and can have specific rules to represent data. STEP also provides various application protocols that represent different knowledge domains within the product lifecycle, which can be included using the òrecipeó approach.

## 4 OUR SOLUTION

STEP has been one of the most successful standards for data exchange. Rather than encode product information into a proprietary format, the STEP standard acts as a data model that can move relatively seamlessly through many software tools. It is being widely used by organizations in many industrial domains. While previously proposed standards focused only on geometric data, STEP covers geometry, metadata, process information, and semantic relationships. As STEP uses EXPRESS language, it can formally describe the structure and correctness of engineering information that needs to be exchanged. Also, STEP is a continuously developing standard and aims to cover most aspects involved in a productôs lifecycle like geometry, topology, tolerances, relationships, attributes, assemblies, configuration and more through different Application Protocols (APs). However, it cannot represent designersô intent since it is mostly context-specific and it doesnôt support decision-making capabilities or consistency checking. On the contrary, an ontology can represent semantic information related to the product in the form of functions, behavior and inferences. Our concept is to combine the implementation of the STEP standard with the development of an ontology to be able to completely exchange product data information with its semantics. The idea is to have a core product ontology at the center of the product lifecycle. This will be a master neutral product definition, which can access, update or modify product data from commercial CAD systems. This eliminates discrepancies in data representation and makes collaboration more effective and preserves the integrity of the data.

For the development of an ontology, we used Protégé. Protégé is an open source ontology editor and knowledge-based framework. It was developed at Stanford University initially for the creation of ontologies for the medical world but evolved into a much more general purpose ontology editor. There are two ways to model ontologies in Protégé but we are interested in Protégé-OWL as it supports the Web Ontology Language (OWL) which is used to develop ontologies. Protégé-OWL is just an extension of Protégé that supports the Web Ontology Language (OWL).

The proposed methodology is that a product model created in a CAD system A is exported as a STEP file (which is represented in EXPRESS format). There are available modules for the import and export of a CAD file in the STEP format for various CAD applications. This STEP file is fetched into Protégé which creates an ontology. We should be able to make modifications on the ontology at this stage through the functions and User Interface supported by protégé. Further, this modified ontology would be exported from Protégé in the STEP format. Finally, this STEP file can be imported into a CAD system B. This STEP file will (ideally) not have any information loss or inconsistency in the product model data when compared to the model created by CAD system A. This methodology is represented in the figure 1(a). Pro/Engineer was used to create a test model and the Pro/E part file is the file used in the translation process.


Fig. 1(a): Ideal translation process

However, in practice, a STEP file generated by CAD system A cannot be directly imported into Protégé. Protégé doesnôt natively support the import of STEP files. So, there should be a mechanism to convert the STEP file into a format that Protégé can import and then, create an ontology to represent the model in the CAD file. To address this, National Institute of Standards and Technology (NIST), has developed a plugin for Protégé called ôOntoSTEPö.

OntoSTEP plugin develops an ontology in Protégé by converting EXPRESS schema to OWL-DL and classifying EXPRESS instances to OWL individual [4]. Only one of the Application Protocols for STEP, AP203, is considered. Krima, Barbau, Fiorentini, Sudarsan & Sriram (2009) present details about the mapping of concepts and instances from a STEP file in EXPRESS language to an ontology in OWL language. In essence, OntoSTEP enables the import of a STEP file into Protégé and creates an ontology from the STEP file representing the product model created in a CAD system.

Furthermore, as already discussed, the ontology created in Protégé needs to be converted back to a STEP file which can be accessed by another CAD system. This is the core issue we are addressing. We are developing a plugin for Protégé which converts the ontology represented in the OWL language into a STEP file in the EXPRESS language. So, the translation is being done from OWL to EXPRESS. Figure 1(b) represents the actual translation process including both the OntoSTEP and our new plugin. As previously considered, CAD system A and CAD system B can notionally be any CAD application.

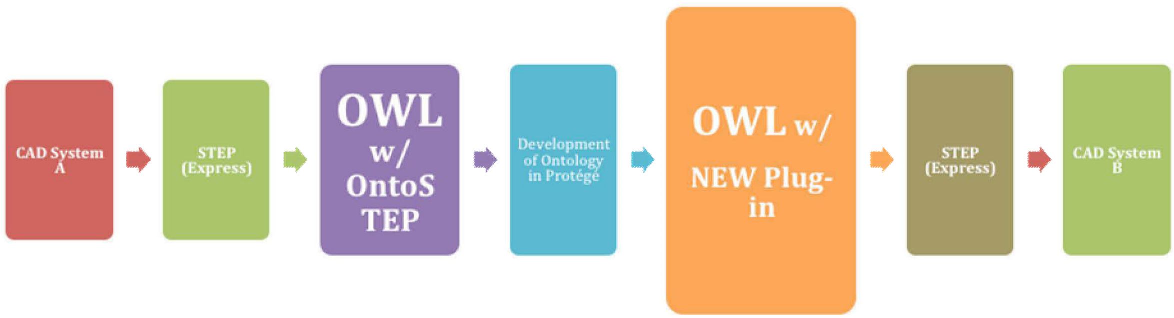


Fig. 1(b): Actual translation process in practice.

For the new plugin to convert OWL to EXPRESS, several mappings have been used between the concepts in both these files. An ontology in OWL is represented as a schema in the EXPRESS language. A class in OWL is conceptually similar to an entity in EXPRESS language. Likewise, a subclass maps to a subtype. OWL has two major types of properties to relate different individuals among themselves and to some literal values. Object properties establish a relation between two individuals and data properties establish a relation between an individual and a literal value. But EXPRESS language doesnît have object and data properties. So, the mapping is done by using an attribute with entity type for an object property and an attribute with simple data type for a data property. Table 1 briefs the mapping concepts.

| OWL | EXPRESS |
|---|---|
| Ontology | Schema |
| Class | Entity |
| Subclass | Subtype |
| Object Property | Attribute with entity type |
| Data Property | Attribute with simple data type |

Tab. 1: Mapping of concepts between OWL and EXPRESS.

For the development of the plugin, OWL-API was used. OWL-API is an open source Java API and reference implementation developed and maintained at University of Manchester. Horridge and Bechhofer (2009) discuss the major components and functionalities of the API. It includes components for creating, manipulating and serializing OWL ontologies. òThe API also has a very flexible design that allows third parties to provide alternative implementations for all major componentsó [3]. As previously discussed, all the data values represented in the STEP file are expressed in the ontology by using the data property axiom and the relationships between individuals by using the object property axiom. OWL-API provides functions for the extraction of data property values and object property values. These functions are used to extract the appropriate data from the ontology and are syntactically represented in the EXPRESS language in the generated STEP file by way of manually generated functions.

## 5 METHODS

There are numerous ways to check the validity of the data conversion process. The validation process becomes rather easy since the conversion follows a roundabout fashion. It means that the initial STEP file created in CAD system A (Pro/E in our case) and the STEP file exported from Protégé from the ontology has to be the same. Thus, there is a concrete basis for comparison and thorough results can be generated. The exported STEP file can be fed into CAD system B and the validation can be performed by checking if the STEP file represents the same model as created in CAD system A. Ideally, the model represented in CAD system B has to be exactly the same model that has been created in CAD system A with no inconsistencies or loss of data.

We used 2 experiments to test the data translation methodology. In the first experiment, we created a test model in in Pro/E. This test model was exported as a STEP file. The STEP file was imported into Protégé via the OntoSTEP plugin created by NIST. The plugin requires importing a related schema file as well. STEP AP203 schema file was imported. OntoSTEP created an ontology represented in the OWL format from this STEP file. Our new plugin translated this ontology back into a STEP file. Further, this STEP file is imported into Pro/E, which was used to create the initial test model. The model represented by this STEP file was compared to the model initially created. The second part of this experiment included the measurement of mass properties like volume, surface area, density, center of gravity, and principle moments of inertia of the test model when initially created in Pro/E. This was compared to the mass properties of the resultant model represented in Pro/E at the end of the process. While there are software tools to validate the translation process, the use of geometric validation properties is an acceptable first step for our purposes here.

In the second experiment, we wanted to address the issue of different CAD systems implementing STEP in a different way and to a different level of completeness. Four different CAD applications were used to create the same test model. A slightly more complicated model was used for this experiment. The CAD application systems used are SolidWorks 2010, CATIA v5, Siemens PLM Software NX7.5, and Pro/Engineer Wildfire 4.0. All of these are commercial CAD software packages and have the ability to import and export STEP standard files either natively or through easily available tools. This test model was converted from the native file format of the respective CAD application system to STEP AP203 ed2. The reasons for choosing STEP AP203 ed2 are that it is the most up to date model that includes Geometric Dimensioning and Tolerancing (GD&T), solid model construction history, and materials data. Further, each of these test models which are exported in the STEP format are imported into Protégé with the help of the OntoSTEP plugin. This converts the STEP file into an ontology in OWL language. Then, our new plugin is used to generate a STEP file from this ontology for each of the four test models created.

As with the first experiment, the generated STEP files have to represent the same test model generated initially in their respective CAD application systems. Both the STEP files are compared against each other to determine if the data conversion process was successful without any inconsistencies or loss of data.

## 6 RESULTS

In our experiments, inconsistencies and missing data have been observed when both STEP files were compared against each other. We believe that the inconsistencies were primarily because of the issues with the ontology created from the initial STEP file through the OntoSTEP plugin. The resulting ontology was observed to be incomplete. Some of the entities and their respective attributes were not translated into the ontology. There was also an issue with the order of attributes in a STEP file. The order of attributes of each entity in a STEP file is important but the generated ontology in the Web Ontology Language (OWL) has no way to represent the order of attributes (which are either object properties or data properties in OWL). Krima et al. (2009) presented some of the limitations of OntoSTEP in their publication òOntoSTEP: OWL-DL Ontology for STEPó. It is stated that functions in EXPRESS language cannot be automatically translated to OWL since it is based on Description Logic without any procedural aspects. Also, most data representation in EXPRESS uses the aggregation type ôListö with varying bounds and EXPRESS defines it at the level of aggregation type while OWL defines it at the entity level.

We started with an experiment where a model file from one CAD system is converted to a STEP file and the same STEP file is being fed back into the same CAD system. A few inconsistencies have been discovered in this process demonstrating the fact that the same CAD system has different ways to interpret a STEP file while importing and exporting it. Pro/Engineer was used for this test. Figure 2(a) shows the 3D model in Pro/Engineer before it has been exported as a STEP file. Figure 2(b) shows the model resulted when the STEP file is imported.

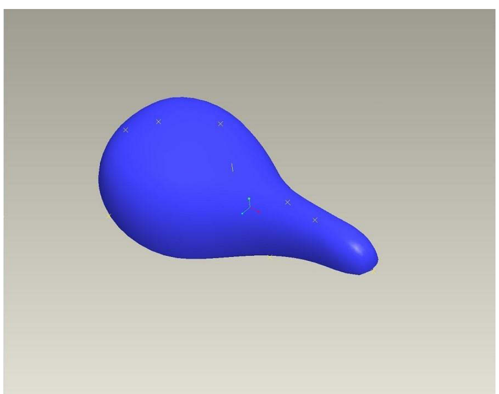

Fig. 2(a): Model in Pro/Engineer.

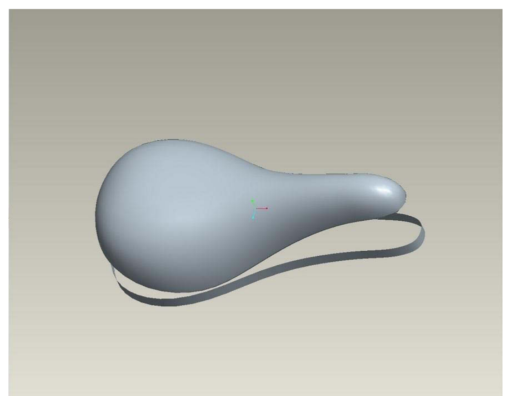

Fig. 2(b): Model imported as a STEP file.

In another experiment, instead of using the same CAD system for exporting and importing a STEP file, we used a different CAD system while importing the STEP file in the last stage of the process. A few inconsistencies were observed but the model looked similar to the model in the previous experiment when the same CAD system was used. This demonstrates that different CAD systems interpret STEP in a different way. Figure 3(a) shows the 3D model in Pro/Engineer before it has been exported as a STEP file. Figure 3(b) shows the model resulted when the STEP file is imported in a different CAD system, SolidWorks.

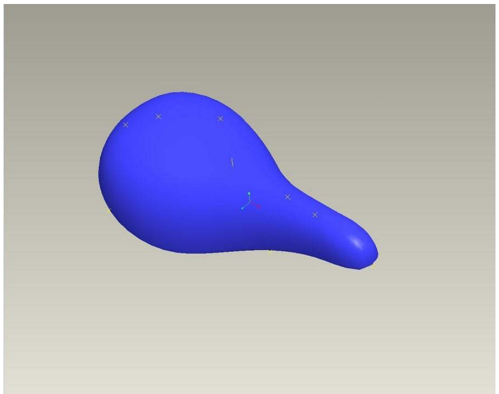

Fig. 3(a): Model in Pro/E.

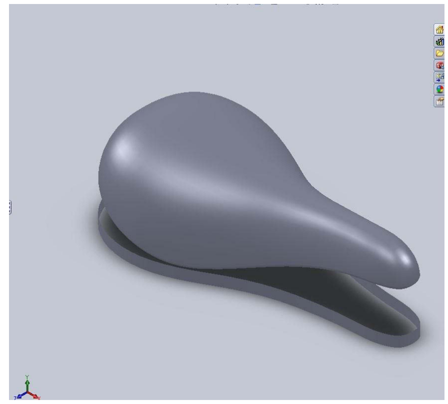

Fig. 3(b): Imported as a STEP file.

In our first experiment with our methodology, the test model created was translated and the STEP file went through the entire process successfully. But it translated into an incomplete model when viewed back in the CAD system. The missing attributes and the limitations of using OWL language, as previously discussed, are probable reasons for this behavior. Figure 4(a) represents the original test model created in Pro/E. Figure 4(b) shows the model represented by the resulting STEP file from our plugin.

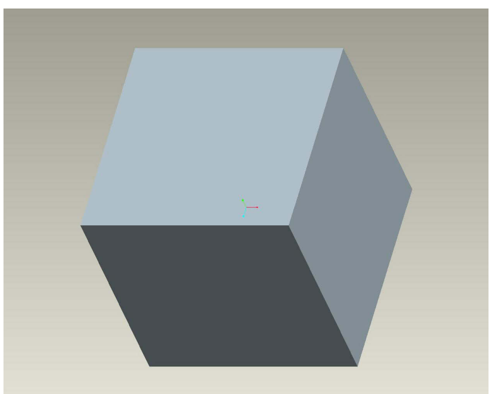

Fig 4(a): Test model in Pro/E.

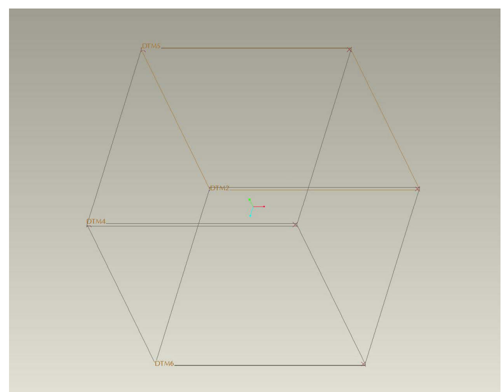

Fig. 4(b): STEP file from our plugin.

The second part of the first experiment included the comparison of mass properties of both the models. Table 2 represents the comparison results.

| | **Original STEP file** | **Generated STEP file** |
|---|---|---|
| **Volume** | 1.2500000e+02 INCH^3 | 0.0000000e+00 INCH^3 |
| **Surface area** | 1.5000000e+02 INCH^2 | 0.0000000e+00 INCH^2 |
| **Density** | 1.0000000e+00 POUND / INCH^3 | 1.0000000e+00 POUND / INCH^3 |
| **Center of gravity** | X = 2.5000000e+00<br>Y= 2.5000000e+00<br>Z = -2.5000000e+00 INCH | X = 0.0000000e+00<br>Y = 0.0000000e+00<br>Z = 0.0000000e+00 INCH |
| **Principle moments of inertia (POUND * INCH^2)** | I1 = 5.2083333e+02<br>I2 = 5.2083333e+02<br>I3 = 5.2083333e+02 | I1= 0.0000000e+00<br>I2 = 0.0000000e+00<br>I3 = 0.0000000e+00 |

Tab. 2: Comparison of mass properties between both STEP files.

In our second experiment, we created the same test model in four different CAD application systems. All the models were successfully exported as STEP files. But when trying to import the STEP file into Protégé through the OntoSTEP plugin, we encountered errors. Two of the four files could not be imported into Protégé. The files that could not be imported are the ones originated from the CAD application packages CATIA and Siemens NX PLM software.

The other two STEP files created by SolidWorks and Pro/Engineer were successfully translated into an ontology by OntoSTEP. This ontology was translated into a STEP file by our plugin. When the resultant STEP file was imported into Pro/E, the model generated was observed to have inconsistencies and missing data. The reasons could possibly be the same reasons as stated earlier. Figure 5(a) represents the test model created in Pro/E and Figure 5(b) shows the model represented by the resulting STEP file from our plugin.

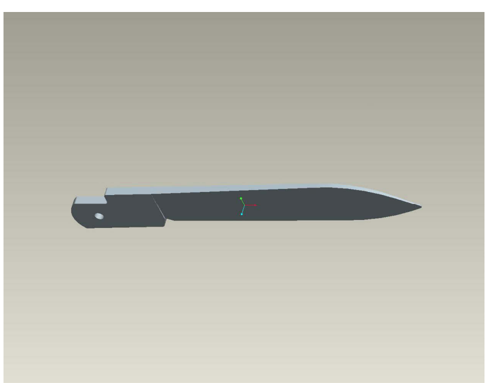

Fig. 5(a): Model in Pro/E.

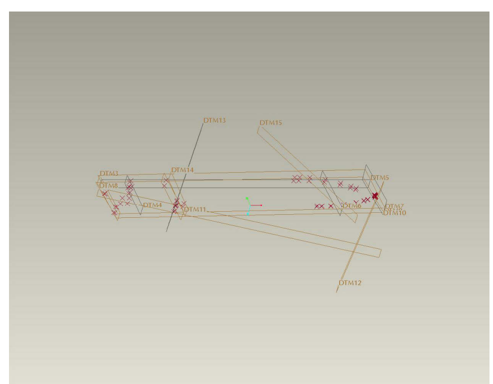

Fig. 5(b): STEP file from our plugin.

In the case of the test model created in SolidWorks, the resulting STEP file from our plugin couldn't be imported back into SolidWorks. A parsing error was reported. The reason for this could be that SolidWorks doesn't accept STEP files with incomplete data whereas Pro/E, as observed from the previous results, imports the STEP file irrespective of the missing data and displays the model accordingly. We also observed the same error with a STEP file that was successfully imported by Pro/Engineer.

## 7 DISCUSSION

The proposed use of the STEP standard and the development of an ontology to represent the product data in STEP format seems to be a viable solution to address many of the problems faced by modern PLM systems, such as the lack of a single standard format for data representation through various phases of a product lifecycle, and disparate software systems and the inability to include semantics, decision-making capabilities, consistency checking and inferencing in data exchange. While the STEP standard represents the data related to the product, the use of an ontology enables the representation of 'beyond geometry' product data information over various phases of the product lifecycle through disparate CAD systems. While AP 219 and 239 could be used for this purpose, the inconsistencies between modern CAD systems from an authoring point of view makes their use problematic.

However, the issues and limitations previously discussed have to be addressed to the level of operability before this methodology can be implemented widely. This level of operability could vary based on the type of data that is to be exchanged. Furthermore, even though STEP is a comprehensive ISO standard that describes how to represent and exchange digital product information, it is not implemented in the same way by all the CAD application systems. This theory was further strengthened by our experiment in which two STEP files from different CAD systems couldn't be imported into Protégé with OntoSTEP. This is a more general issue and needs to be addressed to standardize the application of STEP standard over disparate CAD software packages.

Also, there are proprietary software packages in the market which perform the conversion from OWL to STEP but they are very expensive. On the contrary, all the tools used in the conversion process described in this paper are open source. However, the proprietary software packages might probably be more accurate than the conversion process involving the two plugins with Protégé in some cases. The major reason behind this is that the conversion process discussed here is done at the operational level and not at the geometric level. The relationship between cost and fidelity has been plotted for better illustration. Figure 6 shows a graph representing the trade-off between fidelity and cost. It depicts that when the cost is low, fidelity is also low and as the cost increases, fidelity increases too. Based on the workflow in which the data conversion is involved, each user must decide for themselves which level of data fidelity they need for their current task. Not all use cases will require data to be authored and consumed at the same level of fidelity.

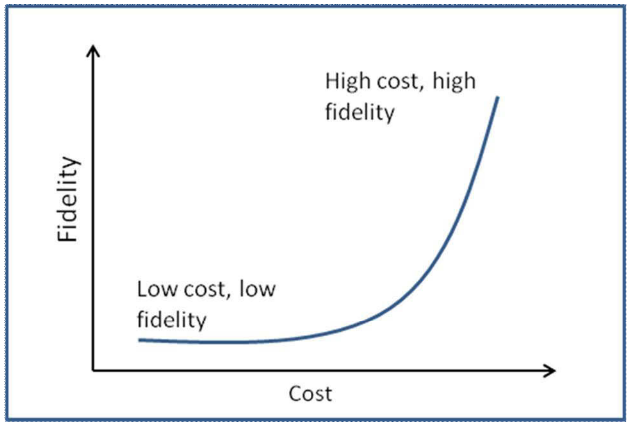


Fig. 6: Trade-off between cost and fidelity.

## 8 CONCLUSION

In this paper, we have discussed the importance of data and semantic interoperability between various CAD systems for efficient collaboration of work and integration of data through all of the phases in the product lifecycle in engineering design. STEP, as a standard for data exchange is already being widely used in industries. However, STEP alone may not be adequate enough to achieve effective data interoperability between CAD systems as it doesnőt support decision making capabilities, consistency checking and inferencing. Hence, we consider the development of an ontology to represent product data and product information with STEP as an intermediate format.

We propose a methodology that involves the creation of an ontology from a native CAD file via the intermediate standard format, STEP using a third party plugin, OntoSTEP, for Protégé software. The details about the development and working of a new plugin to convert the ontology back to a STEP file have been presented. Finally, we acknowledge the issues observed while reading STEP files from certain CAD applications and inconsistencies encountered in the data conversion process along with the probable reasons behind the inconsistencies.

Further research needs to be done to determine the reasons behind the inability of OntoSTEP plugin to read STEP files generated by certain CAD systems and to eliminate the inconsistencies and missing data detected during the data translation. This methodology, when ready to be implemented industrially, has the potential to become an applicable open source solution to most of the data interoperability issues faced in product data interoperability in engineering design.

The future scope of the proposed methodology includes expanding it to include more recent STEP APős like AP 242 that combines the two application protocols AP 203 and AP 214. AP 242 would become the backbone for data exchange, data-sharing, visualization, and long-term archiving.

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