Examining Neutral Formats for Visualization and Data Exchange

Nathan W. Hartman, Ed.D., Adrian Lim
Purdue University, Purdue University
nhartman@purdue.edu, malim@purdue.edu

Abstract

Given the geographically dispersed product design and manufacturing scenarios that are commonplace in industry today, companies are grappling with decisions regarding the use of specific formats and mechanisms to promote communication and collaboration processes. Current solutions tend to center on "lightweight" file formats as one of the enabling technologies that support this distributed collaboration. The recent availability of these visualization file formats has caused confusion and uncertainty in industry relative to their use in specific situations, especially when trying to capture annotations, accurate geometry, and manufacturing information for example. This presentation will discuss work being done to address this challenge by comparing the functionality available (e.g., colors, layers, 3D text, B-rep solids, and assemblies) in the STEP AP 203 E2 format with that found in the current JT, 3DXML , and U3D formats. A discussion of the applicability of these formats based on the findings will also be included.

Introduction

Global design and manufacturing environments are becoming commonplace, with products being designed and manufactured at anytime and in any place. A key link in this process is the ability to communicate information effectively to those people that need it. The medium for communication has changed. No longer are companies sending stacks of drawings to suppliers as their sole method of communication. The use of 3D CAD tools by many product design organizations has lead to the use of the 3D model as a conduit for communication and repository for product information [1]. However, the interoperability within and between CAD systems is a well-documented issue, which causes companies to waste substantial amounts of time and money trying to overcome those problems [2].

In addition to the problems created by differing data formats from native CAD systems, it is not always desirable to share the native CAD file outside the originating organization. As these CAD models are being embedded with corporate intellectual property and design standards, a more secure scenario is necessary to provide customers (both internal and external) with the information they need without compromising the security of the information contained within the CAD model [3]. In most cases, companies might choose neutral standard file formats (e.g., STEP or IGES); however, these formats carry an overhead with them due to robust geometry representations that yield a large file size. As suggested by

Ball, Ding, and Patel [4], [5] and Ding et. al. [6], it is often a combination of traditional standard formats and contemporary lightweight file formats. The novelty of these new lightweight formats has lead to confusion in the user community relative to specific functionality contained in the files and the most appropriate scenarios in which to use these files. This paper outlines an industry-based research project meant to address these concerns.

Project Overview

With the proliferation of CAD visualization formats in the past few years, there has been some confusion in industry with regard to the use of these formats relative to STEP and other standard data formats. As technology vendors advance the capability of "lightweight" file formats, selecting the appropriate file format for a specific purpose is critical to the communication and collaboration process. This project involved a series of tasks that examined the functionality of several of these formats and provided a basis for determining how to use them effectively in various business scenarios. While the scope is not meant to be all-encompassing, it examined issues that have received attention in industry to date. A common theme that pervades this work is informing industry regarding the use and timeliness of the STEP file compared to that of native CAD file formats and more recent "lightweight" formats.

Task 1 in the project dealt with comparing selected lightweight visualization formats (3DXML, JT, and U3D) to the functionality contained with the STEP AP 203 e2 format. STEP stands for the Standard for the Exchange of Product Model Data, and it is used widely in industry for long-term archival of geometry and other design attributes, as well as for data exchange between CAD systems. 3DXML, JT, and U3D are all commercial formats being developed by various software vendors for the communication and dissemination of design information without the mathematical overhead of the native CAD format. In the absence of a standard method for comparing lightweight file formats, the criteria used for evaluating new functionality within the STEP file was used for the comparisons made in Task 1. Task 2 in the project dealt with the development of a checklist that can be used to determine the applicability of particular lightweight formats to a given situation. The research team created a questionnaire to assess the relevant characteristics of lightweight file formats and presented that to relevant experts in industry for feedback. Taking that feedback the survey was revised and then administered to 10 participants at the PDES Inc. Offsite Meeting in April 2008. The results of those interviews were compiled and used to generate a checklist of important characteristics to describe lightweight file formats in an industry usage scenario. Government and aerospace were the primary industry sectors represented in this survey, and it should be noted that these companies are currently the primary implementers of PLM philosophies. Task 3 has just begin at this stage, which is the development of use cases to aid industry in the selection and implementation of lightweight file formats for key tasks, including collaborative design evaluation, request for quote from supplier, and transferring information from design to manufacturing. These use cases will be informed by the work done in Tasks 1 and 2 as a basis for completion.

Task 1: Evaluating 3DXML, JT and U3D According to STEP AP 203 Criteria

Three lightweight file formats – 3DXML, JT, U3D and one STEP file were produced for each test comparison. The first step was to produce a native CAD format with CATIA

V5R17, and a native NX5.0 format. The CATIA file was then used as a basis for exporting into a STEP file, 3DXML file, and U3D file. STEP and 3DXML files were exported with CATIA's 'save as' function. The U3D file however was produced within the Adobe Acrobat 3D toolkit downloaded from Adobe's website. This toolkit that came with Adobe Acrobat 3D is able to import native CATIA file and export it as a U3D file. For the JT file, an NX native file was exported within NX itself. While other CAD systems will generate these types of file formats, NX and CATIA were directly accessible to the authors and represent a substantial share of the market in which these formats are most readily used.

For comparison, STEP files were viewed with CATIA, and 3DXML was viewed with its own 3DXML viewer, and the JT file was viewed with the JT 2 Go viewer. For U3D files however, a PDF file had to be created with the U3D file using Adobe Acrobat 3D, and then viewed with any Adobe reader. For other comparisons that deal with file contents, these files were attempted to be opened with just a plain text editor – Microsoft Window's Notepad. Figure 1 shows an overview of the testing flow path used in this portion of the study.

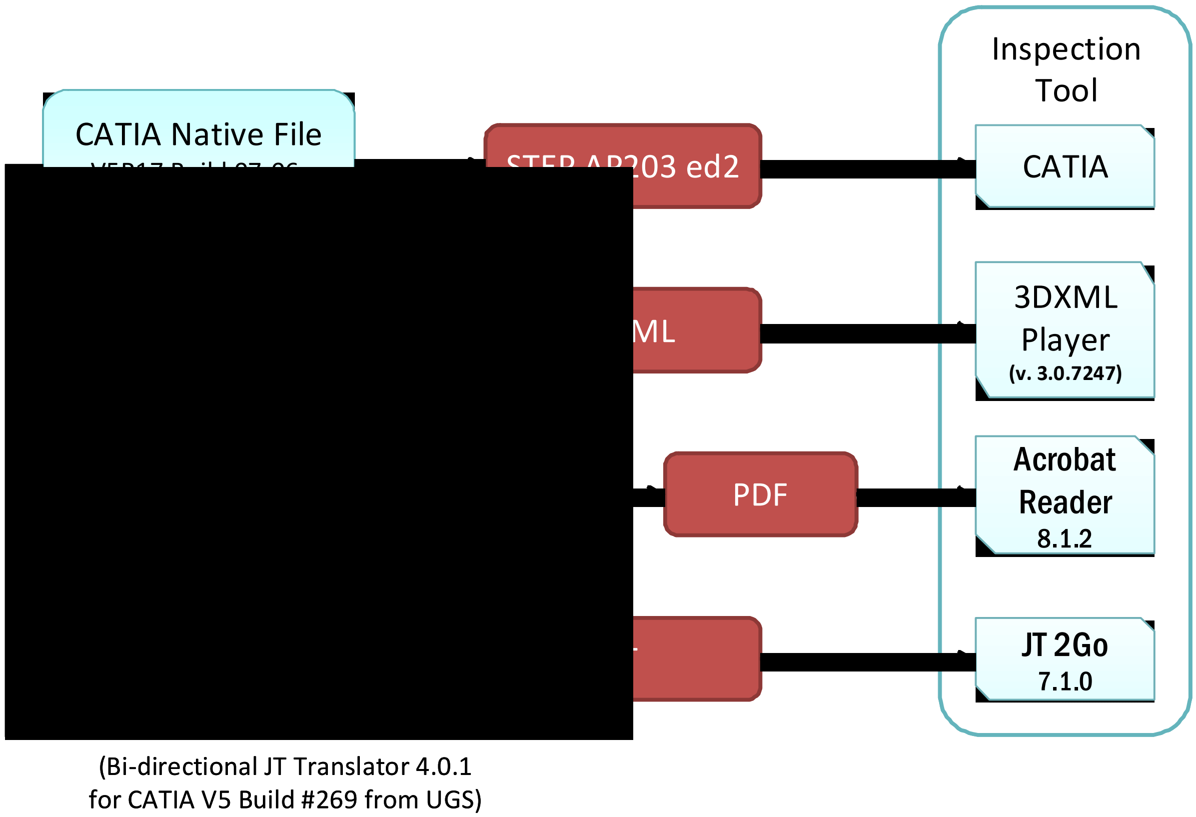
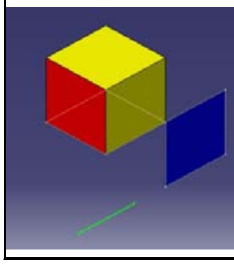
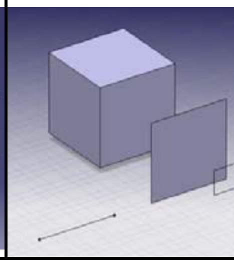
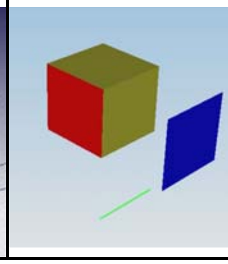
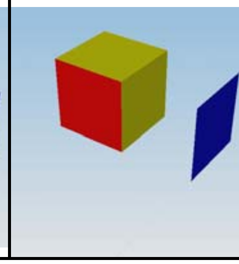
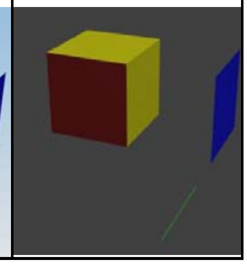


Figure 1: Schematic Diagram for Testing Methodology

Test 1: Colors & geometries

The goal of this test was to confirm that the lightweight file formats support solid colors and different geometry types. A model from the CAx Implementor Forum website (test R18j-C1) is used as a reference for this test. For reference, the CAx Implementor Forum is a subset of the PDES, Inc. group that maintains the STEP file format. A solid cube, square surface, and a straight wireframe line were produced with consistent units. The whole cube was then colored as yellow using the cosmetic functionality within the CAD system, followed by a single red surface on the cube, blue on the square surface, and green on the line. The following screenshots in the table below are the results for this test.

Table 1: Color and geometry test results: STEP file; 3DXML file; JT file; U3D file as PDF.

STEP	3DXML	JT (NX)	JT (CATIA)	U3D
				

It appears that solid colors were supported successfully in all except the 3DXML file format. Simple solid, surface, and wireframe geometries were successfully exported and viewed within each file's respective viewer program.

Test 2: Form features, Construction history

Several features were tested within a same model for Test 2. The model in Figure 2 was produced consistently in CATIA and NX. The rectangular solid extrusion was modeled first, followed by a simple blind hole, a blind hole defined with threads, a counter-bore blind hole, and a counter-sunk blind hole at its respective locations. The goal of this test was to validate if specific form feature properties (e.g., the different hole-definitions) were stored in the file formats rather than plain geometry information. The second objective was to validate if construction history of the model was saved and stored inside the lightweight file as well. Official reference documentations for the three lightweight file formats have no indication of any support for these features [7], [8], and [9].

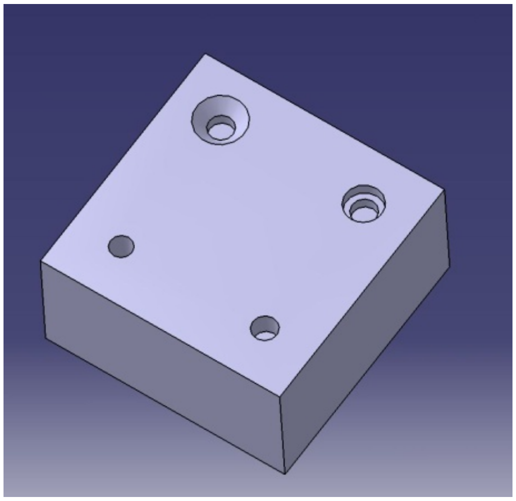


Figure 2: Native CATIA model used for Test 2.

The respective file format viewers were first used to check if any of the form-feature or construction history information can be obtained. The files were then attempted to be opened and read with a plain text editor – Microsoft Window's Notepad.

As expected, no specific form feature information or construction history could be obtained from the lightweight file viewer programs. When the files were opened in a text editor, the STEP file only has a single line of "SHAPE_ASPECT" and no "GEOMETRIC_OPERATION_SEQUENCE" found. This indicated that the STEP exporting function in CATIA did not fully support these two features. It should be noted that future versions of this translator may indeed support such functionality. The 3DXML file had to be uncompressed using a file compression software (i.e. WinZip) before the file could be opened with a text editor. Once uncompressed, contents within the file were inspected. However, no identifiable form-feature or construction history information can be found. For JT and U3D, these files could be successfully opened with plain text editors, and thus its code could not be checked for this test. This is expected from the file format's documentation as it was been indicated that a bit-coding algorithm is needed for translating the files into readable code. The results are summarized in Table 2 below.

Table 2: Summary results from Form Features test

STEP (V5R17)	**3DXML (V5R17)**	**JT (NX 5)**	**JT (CATIA)**	**U3D (V5R17)**
Not translated	Unsupported	Unsupported	Unsupported	Unsupported

Test 3: Mechanical Properties and Geometric Validation Properties

The model used for Test 2 above was re-used for this test. This time, a STEEL material was applied to the model from the native CAD systems' material list before being exported. For geometric validation properties (GVP) comparison, the model properties were first recorded within the native CAD systems. Similar to Test 2, the lightweight files were first inspected with its viewer program for any material ID or GVP properties, and then inspected with a text editor.

For the 3DXML file, no material information could be found within the viewer program. The color of the model however was slightly different from Test 2, indicating that the material's color properties were being stored successfully. Looking at the file's content, the following lines of code were found:

```
<Material xsi:type="BasicMaterialType" name="Steel" ambientCoef="0.2"
diffuseCoef="0.39901" specularCoef="0.9" specularExponent="0.0548643"
transparencyCoef="0" reflectivityCoef="0.3" refractionCoef="1">
```

As shown, only lighting properties of the material were found. No mechanical properties regarding the material could be found. Since there are no tools to inspect for GVP within the 3DXML viewer, the file was opened inside CATIA to inspect for GVP. Table 3 compares the two format's GVP.

Table 3: Results from GVP Evaluation of 3DXML Format

Properties	CATIA native	3DXML	Difference (%)
Volume (m3)	4.957 x 10-4	4.958 x 10-4	0.020173492
Surface (m2)	0.041	0.041	0.000
Cx (mm)	50.054	50.054	0.000
Cy (mm)	50.012	50.010	0.00399904023
Cz (mm)	24.825	24.831	0.0241691843
Mass (kg)	3.896	.496	87.2689938
Density (kg m3)	7860	n/a	n/a

For the JT file format, a limited GVP and mechanical property inspection features are found within the JT viewer. Only centroid information cannot be checked within the JT2Go viewer out of the other properties compared in the following table. All of the other values show close to zero percent difference. It should also be noted that the examination of the JT format required a software key code form the vendor in order to access the desired functionality within the free viewer. See Table 4 for these results.

Table 4: Results from GVP Evaluation of JT Format

Properties	NX 5.0 native	JT (NX)	Difference (%)
Volume (m3)	7829.00	7829.00	0.0
Surface (m2)	0.000803650	0.000803650	0.0
Cx (mm)	0.0500	N/A	N/A
Cy (mm)	0.1000	N/A	N/A
Cz (mm)	0.0250	N/A	N/A
Mass (kg)	6.291779445	6.29178	8.8221e-8
Density (kg m3)	0.077853982	0.077854	2.3120e-7

For the U3D file, no STEEL material was found when the CATIA native file is opened with Adobe Acrobat 3D Toolkit, indicating that the toolkit did not import CATIA's material property successfully. Although another material could be applied to the model within the toolkit, no inspection tool was available to identify the material id or GVP within the PDF file. Table 5 summarizes the overall results of the mechanical/GVP evaluation.

Table 5: Summary results for Mechanical/GVP Evaluation

STEP (V5R17)	**3DXML (V5R17)**	**JT (NX 5)**	**JT (CATIA)**	**U3D (V5R17)**
Not translated	Unsupported (partial)	Successful	Not translated	Not translated

Test 4: Drafting

For this test, the model for Test 2 was used to create a drawing file derived from the CAD model. Standard front-top-side views of the model and an isometric view were captured into the native systems' drafting module. These drawing files were then exported into the STEP format and into the lightweight file formats. These files were then viewed in the corresponding viewer programs.

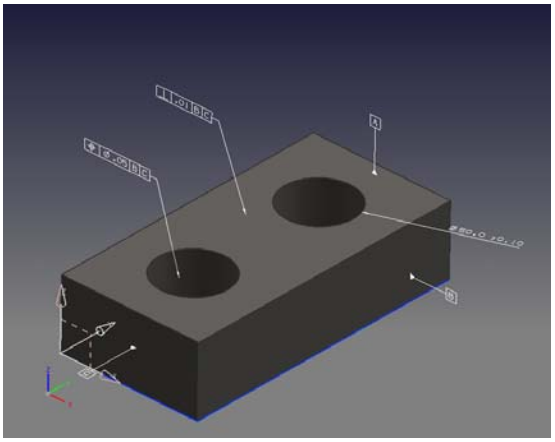
There was no option to export a .CATDrawing file into a STEP file, however his drawing file was able to be exported into a 3DXML file. When viewed with the 3DXML viewer however, the 3D model was displayed instead of the drawing. A similar result was obtained with the JT file where the native .prt drawing file was being exported into JT – only the 3D model of the test object was being displayed. The Adobe Acrobat 3D Toolkit was unable to import a .CATDrawing file. However, it was able to take a .DWG file instead. The CATIA drawing file was then exported as a .DWG, imported into the toolkit, exported as U3D, and finally the PDF was created. With these steps, the drawing was displayed correctly with Adobe Reader. Table 6 includes a summary of these results.

Table 6: Summary of Drafting Capabilities in the Lightweight Formats

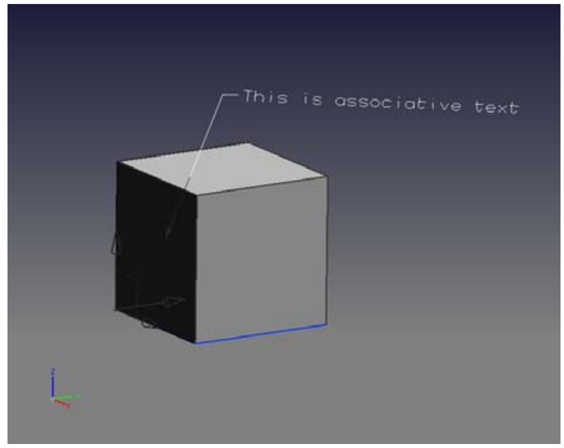
STEP (V5R17)	**3DXML (V5R17)**	**JT (NX 5)**	**JT (CATIA)**	**U3D (V5R17)**
Not translated	Unsupported	Unsupported	Unsupported	Successful

Test 5: GD & T, 3D Associative Text

The purpose of this test was to check for any successful transfer of geometric dimensioning and tolerancing (GDT) information or plain 3D associative text from the native systems to lightweight formats. These types of entities typically fall into a category of entities that have come to be called product manufacturing information (PMI) in industry circles. Native NX files were provided from ATI Corporation for this test, as shown below in Figure 3. Native CATIA files were then reproduced to correspond to the two NX models to be exported. As with previous tests, the exported files were inspected with its respective viewer software.



GD&T on UGS NX native file.



3D text on UGS NX native file.

Figure 3: Native UGS files for testing GD&T and 3D associative text.

None of the converted lightweight files, or the STEP file, showed any text annotation for either of the models when inspected visually with their respective viewer program. The STEP file was then inspected with Microsoft Notepad by searching for the word “text” and “dimension”, such as “ANNOTATION_TEXT_OCCURRENCE” or “DRAUGHTING_PRE_DEFINED_TEXT_FONT”, which would indicate some use of 3D text annotation or GD&T according to the recommended practices documentation from the CAx-IF subcommittee of the PDES Incorporated organization, The search returned no relevant results, indicating that 3D text or GD&T information was not being exported from CATIA. Looking at both the 3DXML file that implemented the 3D text and GD&T, the following similar block of codes are found when the file is being extracted and opened:

```
<Reference xsi:type="ReferenceRepType" id="4"
name="3DText_Annotations3D_ReferenceRep" format="ANNOTATIONS3D"
associatedFile="urn:3DXML:TechRep:loc:1"/>
        <SpecificExtensionSet>

        <SpecificExtension id="1" name="ANNOTATIONS3D">
```

These blocks of code indicated some storage of information regarding the 3D annotation or GD&T that otherwise would not be present, such as in the model in Test 1. This perhaps indicates some storage of information regarding 3D Text or GDT information as an extended feature of the 3DXML format. However, no further information could be found in this particular file. It should be noted that some part of the file was not stored as human-readable code, indicating some storage of encoded information, which could be considered as not being made open. When the researchers referred back to the 3DXML documentation, it did not mention the use of encoded information. Unfortunately, no further investigation can be made on the JT and U3D files as they are not readily readable when opened with a text editor.

In addition, the JT2Go viewer required a key code from the vendor in order to view the desired GDT/PMI information within the JT file. Table 7 summarizes the results for this test.

Table 7: Summary Results of Examining Support for 3D Annotations

STEP (V5R17)	3DXML (V5R17)	JT (NX 5)	JT (CATIA)	U3D (V5R17)
Not translated	Unsupported	Successful	Not translated	Not translated

Discussion

Tests of the lightweight file formats showed many negative results when compared to the STEP file features. Many STEP AP203 ed2 features were not available with the lightweight formats (consistent with supporting format documentation), such as Form features, Construction history, and Drafting capabilities. It is conceivable that some features are not available by default and need to be extended manually. This suggested a difference in the fundamental roles these lightweight formats were built upon compared to the STEP file format. Currently these formats would likely support collaboration and visualization, but need to be enhanced in order to support long-term storage or archival scenarios.

Task 2: Development of a Checklist for Selecting Lightweight Formats

The focus of this task in the research study was to develop a set of metrics (in the form of a checklist) that could be used to determine which of the commercial lightweight formats in questions would be most appropriate to use in a given situation. The importance of this checklist is summarized in the following points:

- No standard method of assessing visualization formats.
- Industry looking for a way to display/store/retain data in lightweight formats
- Some “lightweight” formats are not lightweight
- Visualization formats used in different ways

The research team applied techniques from developing metrics and from developing interviews and questionnaires to construct a survey that was used to gather input from industry expert users. In addition, relevant literature regarding the examination of lightweight formats was also employed. Upon examining relevant literature topics [4], the survey was organized into five sections: openness, extensibility, accessibility, interoperability, and security.

A format is considered **open** if it can be described as widely available, non-proprietary practices, the services implementing the data are explicitly described and documentation of the format and services were readily available, the use of the standardized data and documentation is freely available, the updating process of the associated components were described and well-accepted by the community of involved parties and all organizations are able to participate in the ballot process, the responsibility for maintaining the standard are clearly defined and held by a responsible organization, and the open standard and its documentation are not restricted by royalties, patents, or other internet protocol (IP) restrictions, are publicly available (independent of citizenship or membership in a specific organization or Community), and, if copyrighted, are available at reasonable cost [10]. **Extensibility** is defined as a system design principle where the implementation takes into consideration future growth [11]. **Accessibility** is defined as the act of ensuring that access to information is available to the widest possible audience [12]. **Interoperability** is defined as the ability of a system or a product to work with other systems or products without special effort on the part of the customer, which is made possible by the implementation of standards [13]. **Security** is defined as measures taken to guard against espionage or sabotage, crime, attack, or escape [14].

Based on these characteristics, ten industry experts were interviewed during the PDES Offsite Meeting in April 2008 based on their expertise, their regular use of lightweight formats, and their representation of particular industry segments. The objective was to determine if this initial rubric for lightweight formats matched the expectations and experiences had by industry experts. The industry segments represented in these results are government, aerospace, manufacturing, defense, consulting/professional services. Conspicuously missing from this group is automotive and consumer products sectors. Representatives from these segments are actively being sought and will be included in the final report for this project. The questionnaire was characterized by Likert scale responses (1=low, 5=high) and open-ended questions. In an effort to gain a broader industry response, efforts to gather automotive and consumer products sector input are ongoing.

Results

Table 8 and Table 9 show summary data related to the responses given by the participants. Table 8 shows the average rating for each characteristic, while Table 9 shows the average rating for each industry segment.

Table 8: Average Ratings for Format Characteristics for All Participants

	Openness	**Extensibility**	**Accessibility**	**Interoperability**	**Security**
AVERAGES	4.25641	4.1	4.068966	4.428571	4.2

Table 9: Average Ratings for Format Characteristics in Industry Segments

INDUSTRY	**Openness**	**Extensibility**	**Accessibility**	**Interoperability**	**Security**
Aerospace	4.10	3.83	4.05	4.375	4.33
Government	4.75	4	4.33	4.5	3
Consulting	4	5	4	4.66	5
Manufacturing	4.75	3	4	4	1
Defense	4.08	4	4.11	4.56	5

Table 10 shows the industry segment that considered each format characteristic as the most and least important.

Table 10: Maximum and Minimum Ratings for Format Characteristics

	Openness	**Extensibility**	**Accessibility**	**Interoperability**	**Security**
MAX	4.75	5.00	4.33	4.67	5.00
	Manufacturing/ Government	Consulting	Government	Consulting	Consulting/ Defense
MIN	4.00	3.00	4.00	4.00	1.00
	Consulting	Manufacturing	Consulting	Manufacturing	Manufacturing

As a result of the ratings collected in the Likert-style questions and the responses gathered during the open-ended questions, a rubric emerged that allows users to compare file formats relative to important criteria. Figure 4 represents the final rubric that was developed as a result of the participants' responses.

Visualization Format Metrics	No	Partial	Yes
OPENNESS			
Is it a proprietary format?			
Does the format have an explicity described implementation method?			
Does the format have documentation & services pertaining itself?			
Is the format publically available?			
Totals			
EXTENSIBILITY			
Does the format have the ability to contain various types of geometry?			
Does this format support validation?			
Does this format support animation?			
Does this format support assemblies?			
Does the format support annnotations?			
Does the format support geometric dimensioning and tolerancing (GD&T)?			
Does the format support various forms of graphical properties?			
Does the format retain metadata?			
Totals			
ACCESSIBILITY			
Does the format need to be viewed in a specific viewer?			
Can the format be edited with a simple text editor?			
Can the training for this format be achieved in a limited time relative to the capacity of the format?			
Totals			
INTEROPERABILITY			
Does this format have a broad functionality?			
Can this format be applied to its intended application without the use of add-ons?			
Totals			
SECURITY			
Can this format be secured with passwords?			
Can this format be secured by using estimated geometry?			
Can this format be IP restricted?			
Can this format handle limited use technologies?			
Totals			

Figure 4: Rubric for Assessing Lightweight Format Characteristics

Discussion

Based on these results, it is clear that the importance and relevancy of certain characteristics varies by industry segment. Industry is looking for a complimentary lightweight format to go along with standardized formats. They would also like the ability to edit levels of detail and functionality given the different needs for lightweight formats within organizations. The rubric should help users quantify what is needed by their business, and it should be adaptable to other lightweight formats (and not necessarily just the ones examined in this study). Additional details will be given in the final report for this project as more input from the automotive and consumer products sectors is sought.

Summary

Examination of lightweight visualization formats relies on the use of viewing technology that could come from multiple sources. Due to the examination methodology selected for this study, the researchers only used the free viewing technologies provided by the CAD vendors. Therein lies a potential issue that needs to be addressed in future studies – low-cost or free viewers (vis-à-vis less functional viewers) compared to higher-cost, (potentially) more functional viewers. However, this issue may ultimately be addressed by the user community as they migrate towards the technology that provides the best cost/functionality ratio. Another factor that must be considered in a study such as this is the separation between viewer functionality and the functionality that persists within the format upon translation. An example of this can be seen in the current work being undertaken by ISO in searching for a lightweight visualization complement to the STEP file when used for data archival and retention.

In addition to the more obvious tuning of the STEP standard (as a neutral format), which has been relatively optimized for information exchange between different CAD systems, these lightweight formats were built for mainly presentation or visualization purposes for even non-CAD users. These can be seen in features such as better lighting systems for a more visually appealing model, robust integration with commonly used software, such as word documents, web browsers, or PDFs; compression technologies for efficient file sharing, and even support for animation. In addition, the lightweight formats seem to support some level of file compression and basic support for varying the level of detail included in the file.

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Biography

NATHAN W. HARTMAN is an Associate Professor in the Department of Computer Graphics Technology at Purdue University. His research interests include the use of constraint-based CAD tools in the design process, interoperability and 3D data exchange, and the use of virtual reality in PLM environments.

ADRIAN LIM is currently a Master's student at Computer Graphics Technology at Purdue University. He received his BS in mechanical engineering from Purdue in 2005. His current research focuses on extending and evaluating the exploded view method to visualize complex CAD assembly information, lightweight visualization file formats, and user interfaces.