ANALYSIS AND VISUALIZATION OF COMPLEX COMPUTER AIDED DESIGN MODELS AS A DESIGN STRUCTURE MATRIX

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ABSTRACT
Computer Aided Design (CAD) Systems are large and complex software systems with feature-based solid modelling, NURBS surfaces, sketching, and constraints management functionality and capture knowledge and design history throughout the lifecycle of the design process. Innovations in software and hardware technology help increase the efficiency with which CAD models can capture the overall design process. Representing component geometry as well as features, design parameters, design rules, part dependencies in an assembly context as well as modelling history makes these models large and complex. As the complexity and size of these models increases so is the cost to create, maintain and change them. To reduce the complexity and overall cost, organizations look for design checking and fixing tools as well as viewing and analysis tools. This paper focuses on analysing and understanding CAD model complexity as well as documenting the design process using Design or Dependency Structure Matrix (DSM) methodology.

Keywords: CAD model, DSM, feature based design, CATIA V5, CAA, complexity, Lattix

1 INTRODUCTION

Complexity in a CAD model depends on the complexity of the geometry modelling process, design domain, number of geometrical and non-geometrical features being modelled as well as on the technical skills of the designer. Shikare (2001) identifies the complexity of large 3D geometric models based on the classification of geometric models by Forrest (1974). Forrest classifies geometric models along geometric complexity (lines, planes, curves, surfaces etc.), combinatorial complexity (number of components, edges, faces, etc.) and dimensional complexity (2D, 3D, etc.). Aerospace and Automobile components are categorized as models with high geometric and combinatorial complexity. Most of the current CAD systems are functionally capable of modelling and creating large design models that can be classified under one or more of the complexity categories listed above.

Tools and methodologies for analysing, checking, viewing and reducing complexity of these design models help the designer in validating, documenting and understanding the design process. They also help reduce lengthy error checking processes, provide quick turnaround in design change management which in turn leads to accelerated manufacturing cycle time and improved design documentation. Eustache et al. (2001) propose using Constrained Hierarchical Graph (CHG) as a central product model to understand and manage complexity in a CAD environment. A DSM of a product model provides a concise representation and easy visualization of the design model. This paper proposes a method to create a dependency model of CAD model structure which includes geometry, features, parameters, design rules, constraints and part interdependencies in a commercial CAD system. This dependency model is then analyzed in Lattix DSM (2010) tool to extract the procedural feature based modelling history as well as the construction process of individual features. The results of DSM analysis in Lattix are then used as a baseline for extracting, understanding and documenting the overall design process. The CAD system chosen is Dassault Systems' product CATIA (Computer Aided Three Dimensional Interactive Application) Version 5 also known in short as CATIA V5.

2 CATIA V5 PRODUCT STRUCTURE MODEL

There are many commercial CAD Systems in the market. Some of the significant players are Siemens, Dassault Systemes, Autodesk, Parametric Technology Corp. (PTC) and Bentley Systems. One of the successful CAD systems that adopted Feature Based Design Paradigm is Dassault Systems' CATIA. And CATIA Version 5 is one of the primary CAD system currently used in Boeing. Catia V5 Product Structure Model is composed of a Root Product and many components that are either other products and/or parts. Each product in turn can contain other products or parts. And each part contains one or more geometrical features, geometrical feature sets, axes, sketches, design parameter and rules (Dassault Systemes, 2009). All of this is represented in a specification tree and a model viewer for rendering the geometry.

2.1 Product document structure

A product is something that can be designed and manufactured. CATIA product document is an assembly of other Product and/or Part documents that make up the final product. The final product assembly is represented as a tree. Figure 1 shows the typical structure of a CATIA V5 Product document.

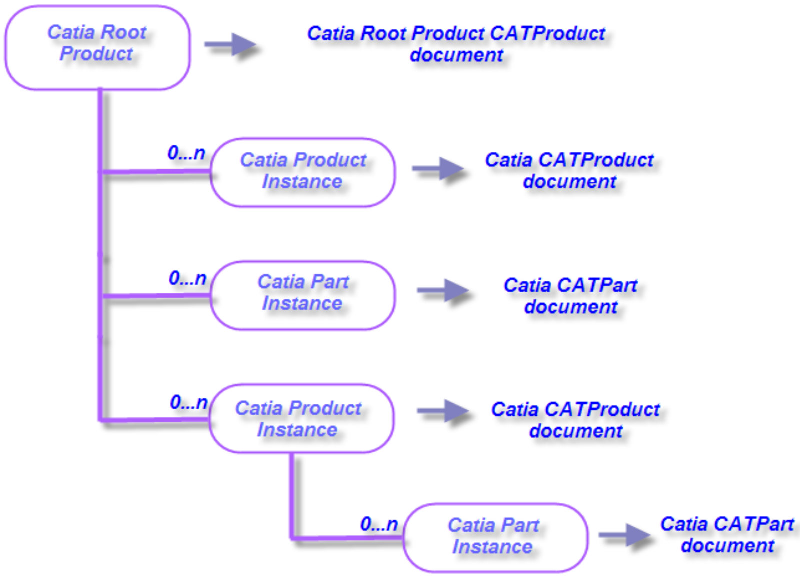

Figure 1. Structure of a CATIA V5 product document

2.1 Part document structure

Part feature (Figure 2) is the root feature of the part document; it contains the design process of the component being designed. It aggregates three reference planes that are required to define the axis system for the part being designed. It also contains the following geometrical feature sets:

- ***PartBody*** → a required Solids feature set, represents main part geometry
- ***Body*** → an optional Solids feature set, can be 0 or more
- ***GeometricalSet*** → an optional Surfacic feature set, can be 0 or more
- ***OrderedGeometricalSet*** → an optional Surfacic feature set, can be 0 or more

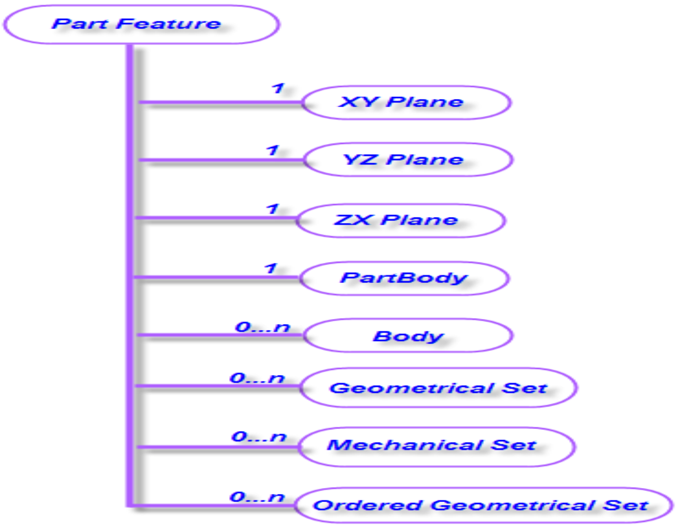

Figure 2. Structure of a CATIA V5 part document

In addition to capturing the hierarchical structure of the product, the product structure model also captures interdependencies between the features. These interdependencies represent the geometrical modeling process used to design the part. Figure 3 shows the CAD model complexity of an Airplane Fuselage Section with over 3000 features, parameters and rules which makes it impossible to visualize and understand the model tree as a whole. Size of this model is approximately 75MB. Each of the geometrical features has a B-Rep/topology perspective and can be represented by vertex, edge, face and volume. These topological dependencies further add to the complexity of the overall CAD model. Model complexity makes it difficult to understand the design intent and as well as the geometry modeling process. Generating a Design Structure Matrix (DSM) of the CAD model significantly helps in improved visualization of the model structure as well as in understanding and analyzing the overall design process.

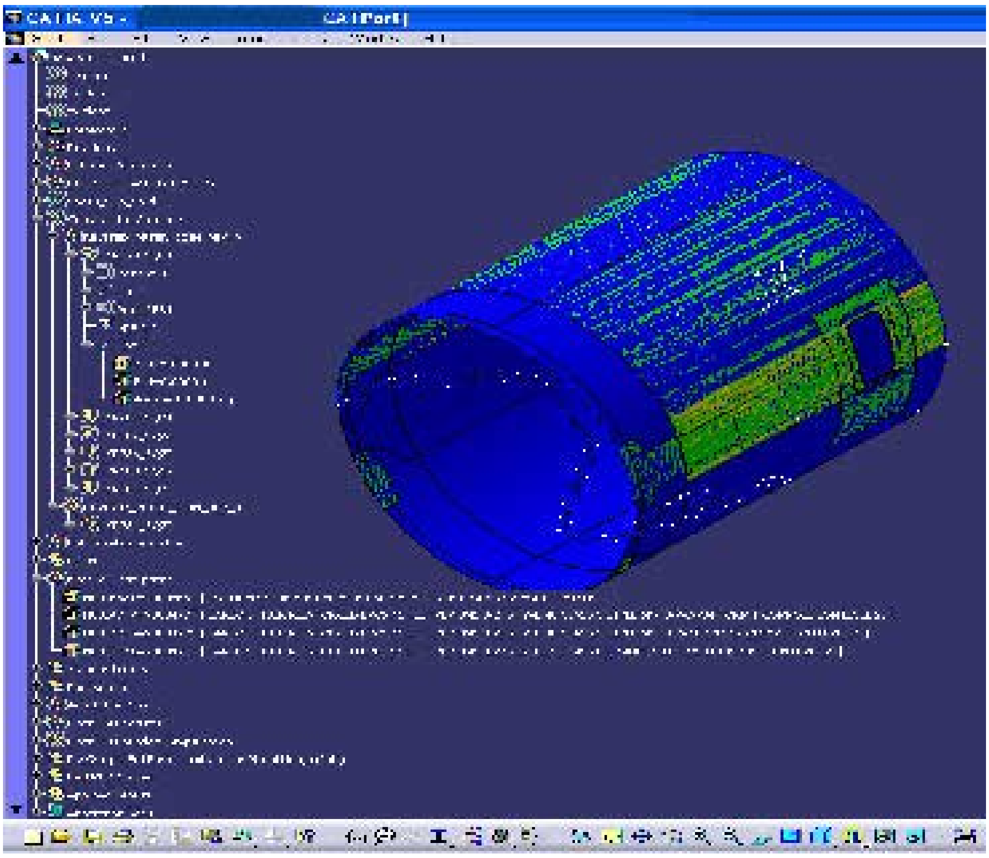

Figure 3. Aircraft fuselage section CATIA V5 CAD model complexity (over 3000 features)

3 CAD MODEL AS A DSM

For generating DSM of a simple CATIA V5 model, a simple model is manually read to identify all the features, feature sets as well as non-geometric and product entities. This data is then used to manually create a DSM inside Lattix tool for analysis. Manually generating a DSM from large and complex models is in itself a complex process and the resulting DSM may not accurately capture all the dependencies. Lattix DSM tool and CAA (CATIA or Component Application Architecture) V5 API (Application Programming Interface) can be used to automatically generate DSMs for such complex models. CAA API (Dassault Systemes, 2009) can be used to programmatically identify and extract features and any dependencies between them. These features and their dependencies are then programmatically represented as DSM elements using Lattix LDI (Lattix Data Import) interface (Figure 4). Lattix LDI module allows the creation of large DSMs from an XML file in LDI format (Lattix, 2010). Once the DSM is created as a Lattix LDI/XML (XML, 2008) representation, then the model is analyzed in Lattix using DSM techniques. Figure 4 shows the overall architecture of this process. There is also a potential possibility of creating CAD models by reverse engineering a DSM model. More research is required in this area to generate a proof of concept and this is beyond the scope of this paper.

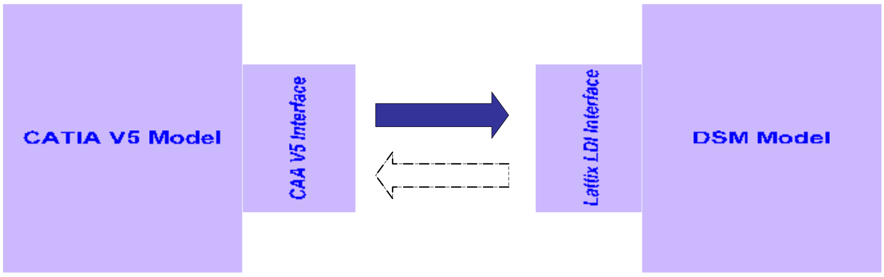

Figure 4. Generating DSM using CAA V5 and Lattix LDI

Figure 5 shows a simple example of a CAD Model along with its corresponding DSM representation. Each of the features in the CAD Model is represented as an element in the DSM. These elements can be geometric, non geometric as well as product entities. A hierarchical DSM can concisely capture the product structure along with its geometric and non geometric entities. In this particular example, feature dependencies are identified and marked in the DSM manually.

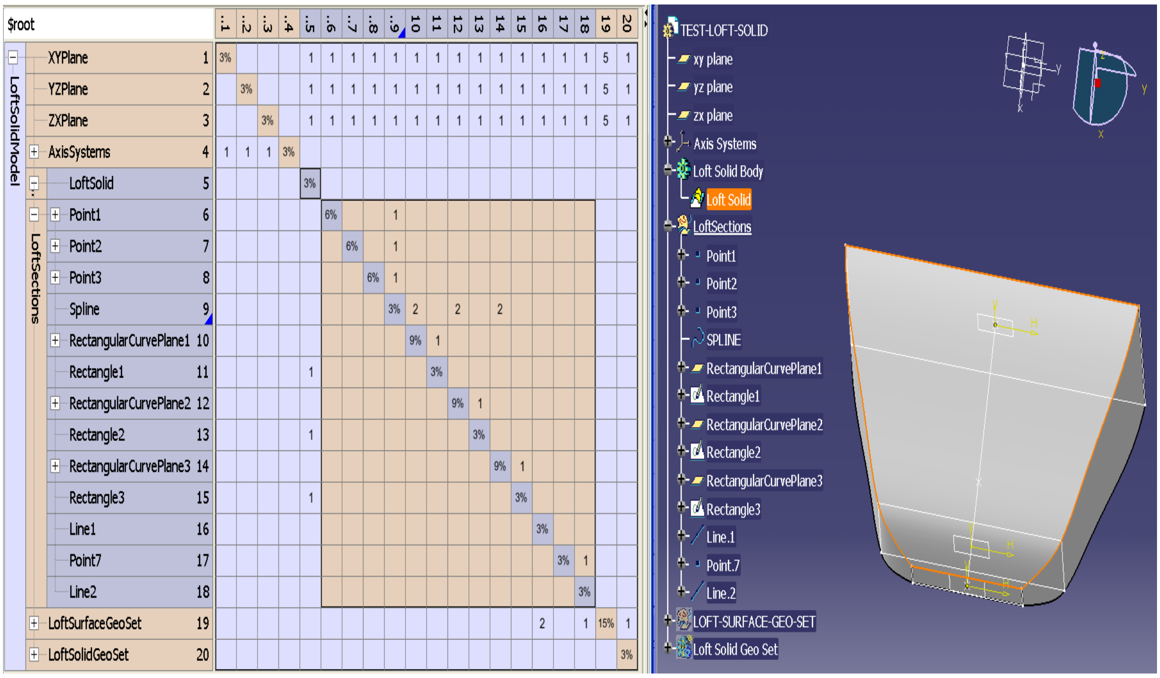

Figure 5. Sample CAD model & corresponding DSM

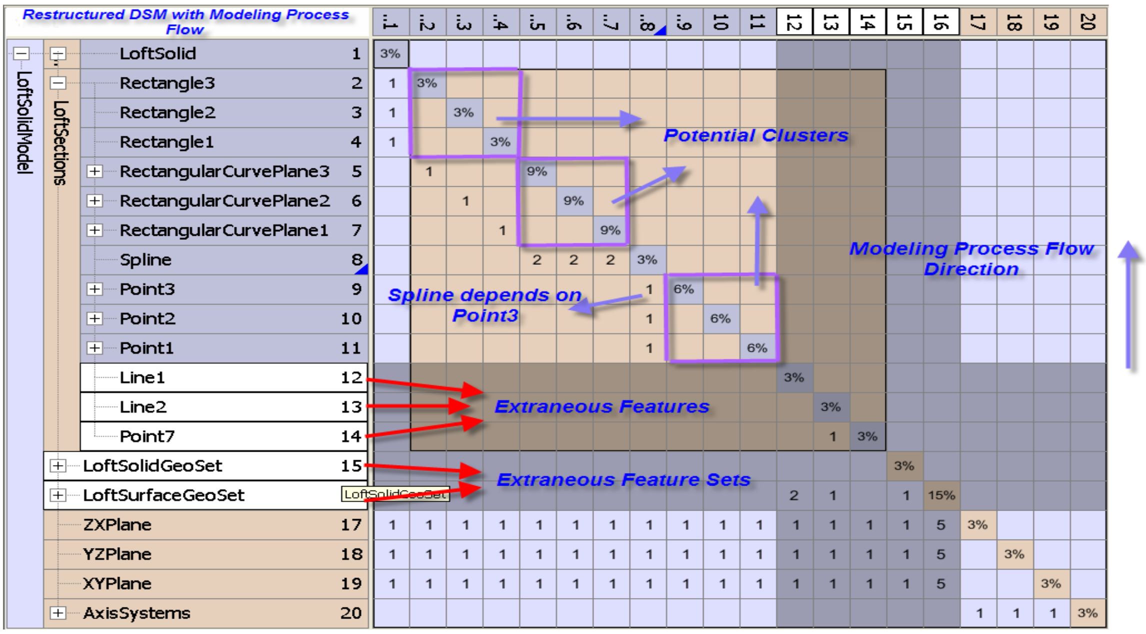

Figure 6. Restructured DSM depicting the design process & extraneous features of the CAD model shown in Figure 5

Once all the dependencies are identified the DSM is analyzed by applying partitioning and clustering algorithms. Applying partitioning algorithm moves heavily used features and their closely related dependencies to the bottom of the DSM. And closely connected features are grouped together to form a potential cluster. Combination of different DSM techniques can be used to restructure and simplify the Model Structure. A restructured DSM of the model shown in Figure 6 identifies possible feature clusters as well as the hierarchical structure of the product. DSM analysis can also highlight any extraneous features and aids in cleaning up the model as shown in Figure 6. Features that are heavily dependent on other features tend to move to the top of the DSM. Top most feature of the Model is typically the end result of the modeling operation. The numbers across the diagonal of the matrix display the size of a feature or a feature set as a percentage of the total number of features in the model. By recursively applying these DSM techniques at different hierarchical levels of the DSM, the essence of the modeling process can be extracted. Figure 7 shows overall modeling process as a DSM.

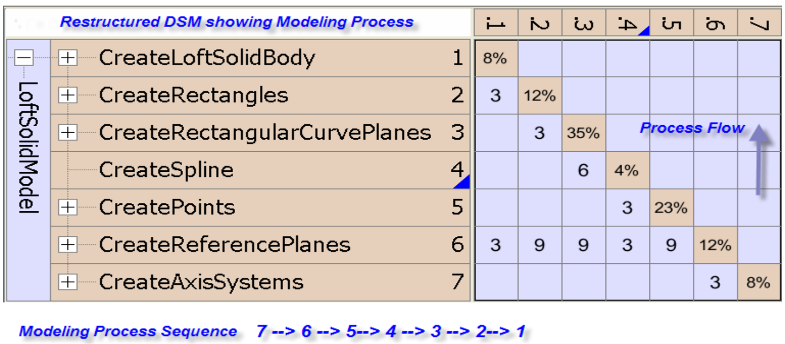

Figure 7. CAD modeling process as a DSM

4 DSM ANALYSIS OF CAD MODEL: ADVANTAGES

Visualization of the CAD model as a DSM significantly reduces the complexity by capturing the design intent. Classical DSM techniques can be applied to analyze and recommend design process improvements.

- DSM techniques can be used to document the overall design and geometry modelling process used to design a product.

- Design history along with parametric representation of the design process as a DSM can be used in Engineering change management process and in impact analysis.
- Capturing parameter and feature dependencies enables in identifying clusters of the modelling process and also helps in identifying the design sequence.
- Identifies duplicate and redundant features, parts and parameters.
- Design modelling clusters can be reused thus reducing the overall design time.
- DSM based modular design methods (Xiaoxia, 2008) can be applied to CAD model DSM representations to create virtual modular architectures of the CAD model processes leading to improved design efficiency.
- DSM analysis eventually helps improve project planning of the design project, enhances design process reuse at different levels as well as helps understand assembly structures.

5 CONCLUSION AND FUTURE WORK

This paper presents a novel approach to analyze, understand and restructure complex CAD models using DSM techniques. The CAD system chosen for this approach is Dassault Systemes' CATIA V5 and assumes availability of open access to CATIA V5 modelling kernel. Most of these concepts can be applied to other CAD systems such as Siemens UG/NX, Bentley, AutoCAD etc. provided there is programmatic access to their modelling kernels. The DSM example presented in this paper is created manually from a simple CATIA V5 model. Manually creating a DSM for large and complex models is impossible; and this is a limitation. A software system needs to be developed to automatically generate DSMs for large and complex CAD models, like the one shown in Figure 3. This system should also be able to capture dependencies from auxiliary feature information such as B-Rep data, dimensions etc. A future extension to this work could be to research into the possibility of using DSM representation as a neutral representation for transferring geometrical data and modelling process among disparate CAD systems. A dependency model can also potentially be used as a single source of design representation to facilitate adoption of design process changes to multiple CAD environments.

REFERENCES

Dassault Systemes (2009). *CAA V5 Encyclopaedia*, Version 5 Release 20. Dassault Systemes.

Eustache, J., Maranzana, R., Lanuel, Y. & Gardan, Y. (2001). Managing Complexity in a CAD Environment. In Change Management and the New Industrial Revolution. In *Proceedings of IEMC'01* (pp. 104-109).

Forrest, A.R. (1974). Computational Geometry – Achievements and Problems. In *Computer Aided Geometric Design* (pp. 17-44). Academic Press.

Lattix (2010). Lattix Knowledge Base, Version 6, http://kb.lattix.com/module/ldi/version6. Lattix Inc.

Shikare, D. (2001). Complexity of Geometry Models. A Survey by National Centre for Software Technology (NCST), Mumbai, India. http://www.angelfire.com/space2/dineshshikhare/writings/geom_complexity.pdf.

Xiaoxia, L. & Gershenson, J.K. (2008). DSM Based Product Representation for Design Process Modularity. In *ASME Conf. Proceedings* (pp. 309-321), DOI:10.1115/DETC2008-49963

XML (2008). Extensible Markup Language (XML) 1.0, 5th edition, http://www.w3.org, W3C Recommendation.

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Analysis and Visualization of Complex Computer Aided Design Models as a Design Structure Matrix

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Computer Aided Design

- Computer Aided Design (CAD) tools are designer assistant softwares
- Used by large Automotive, Aerospace and other design and manufacturing industries
- Using latest software technologies CAD systems can not only model geometry but also capture design history, features, design parameters, constraints and part dependencies in an assembly context
- CAD Systems can generate 2D/3D wireframe models, complex surface and solid models
- There are many commercial CAD Systems in the market. Some of the significant players are Siemens, Dassault Systemes, Autodesk, Parametric Technology Corp. (PTC) and Bentley Systems

CAD Model Representation

A typical CAD Model represents:

- Hierarchical structure of the product
- Feature Interdependencies
- Geometric Modeling process
- Design parameters, rules, constraints
- Design Data as design tables
- 2D geometry as Sketches
- 3D geometry as points, curves, surfaces & solids
- And Topological structures (i.e. vertex, edge, face etc.)

CAD Model Complexity

- CAD Model Complexity depends on:
  - Design Domain
  - Geometry Modeling process
  - Number of Geometrical Features
  - Number of Non-Geometrical Features (i.e. parameters, rules etc.)
  - Technical skills of the Designer
  - Aerospace models have high geometric (curves, surfaces etc.) & combinatorial complexity (number of components, edges, faces etc.)

CATIA V5 Product Structure Model

- Dassault Systemes' CATIA (**C**omputer **A**ided **T**hree Dimensional **I**nteractive **A**pplication) Version 5 is one of the primary CAD Systems used in Boeing
- It is a Parametric Feature Based Modeler
- CAAV5 (Component or CATIA Application Architecture) is the underlying architecture of the CATIA Modeler
- CAAV5 framework can be used to develop customized design solutions
- CATIA Product Structure Model is composed of a Root Product and many components that are other products and/or parts
- Each product in turn contains other products or parts as a hierarchical structure

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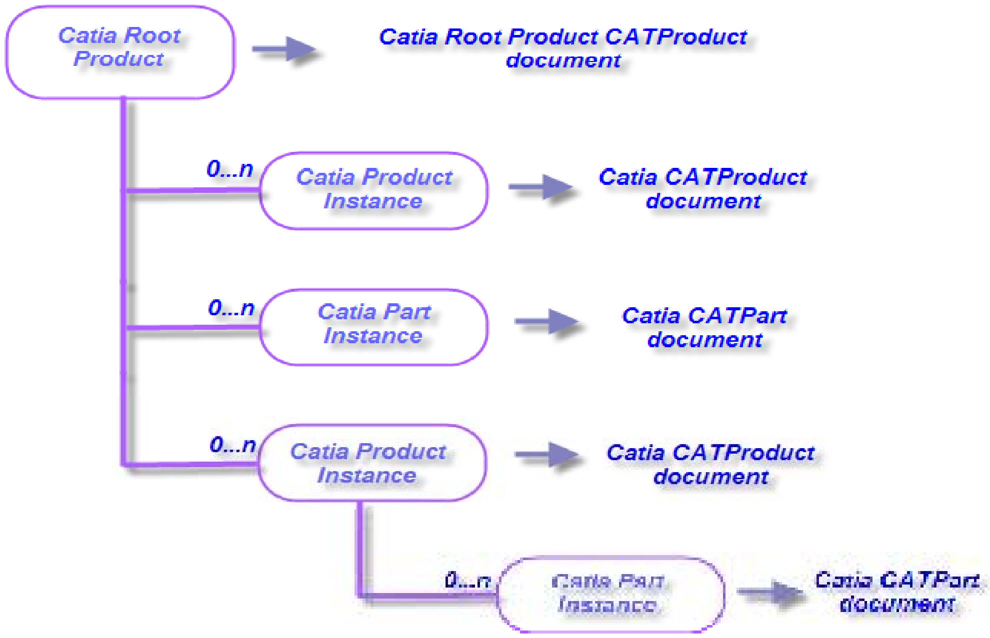
CATIA Product Document Structure



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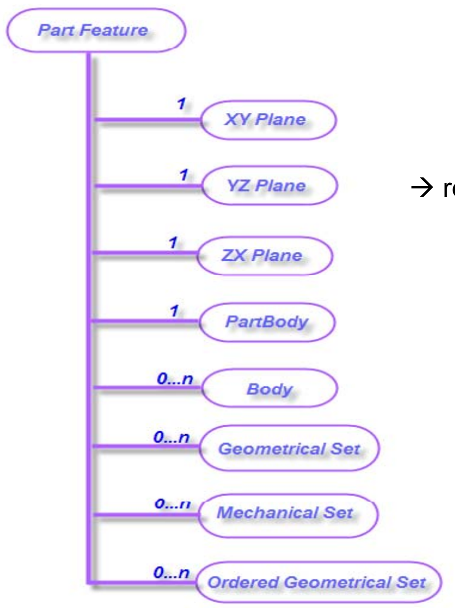
CATIA Part Document Structure



→ reference planes representing Part Origin in 3D Space

→ a required Solids feature set, main part geometry

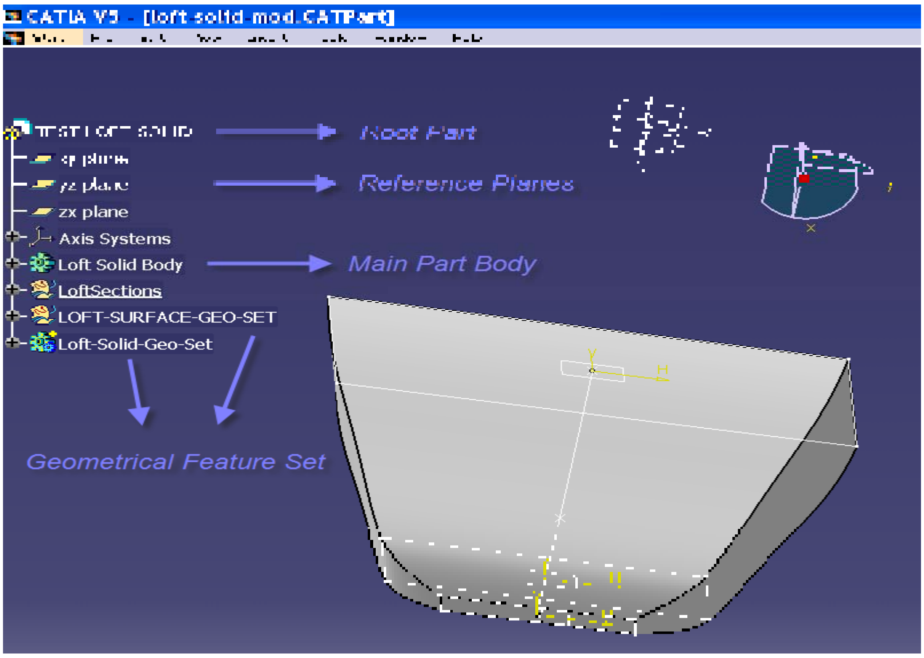
→ an optional Solids feature set, can be 0 or more

→ an optional Surfacic feature set, can be 0 or more

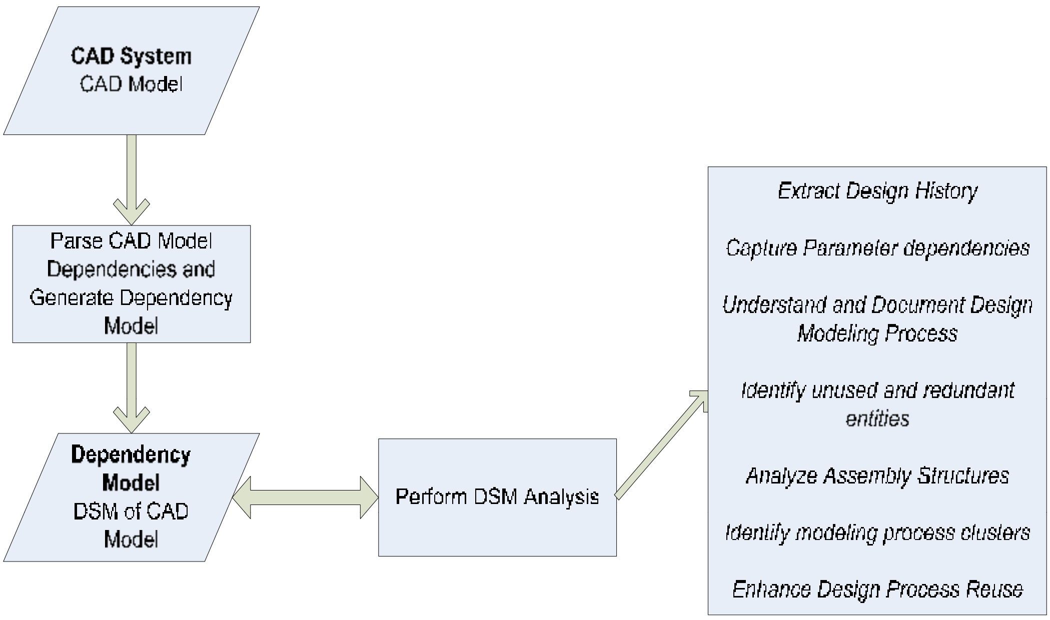
→ an optional non geometrical feature set

→ an optional Surfacic feature set, can be 0 or more

Sample CATIA V5 Model



CAD to DSM Overall Process



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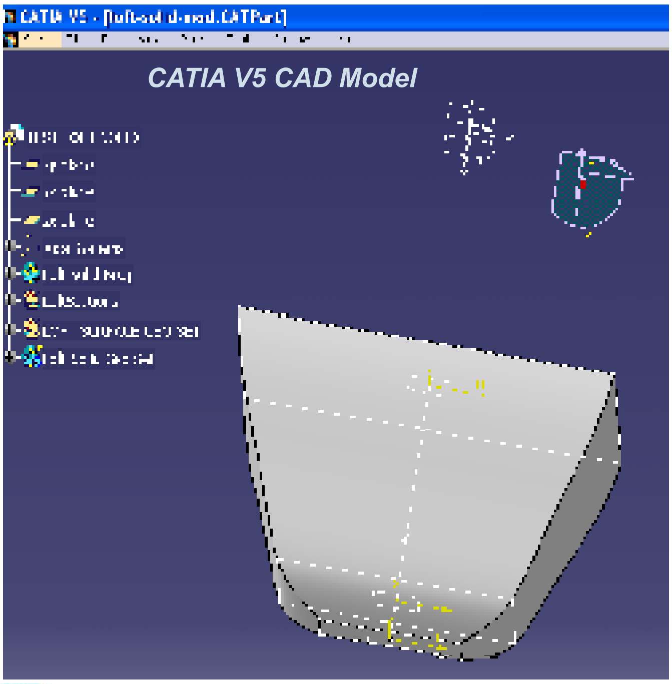
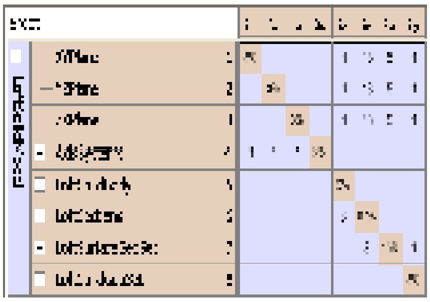
DSM of a Simple CAD Model



Corresponding DSM Model



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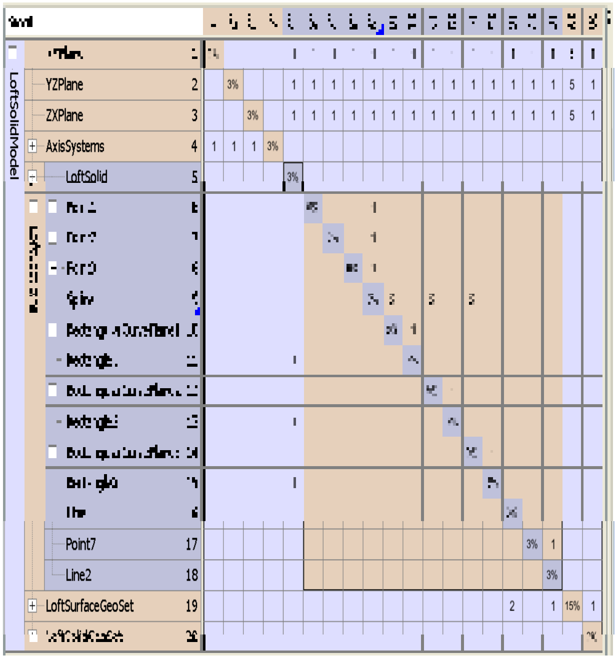
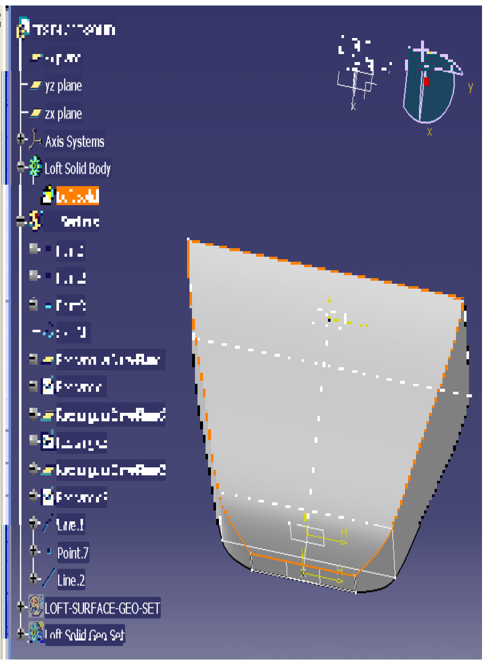
As-is DSM of a Simple CAD Model (Cont‘d)





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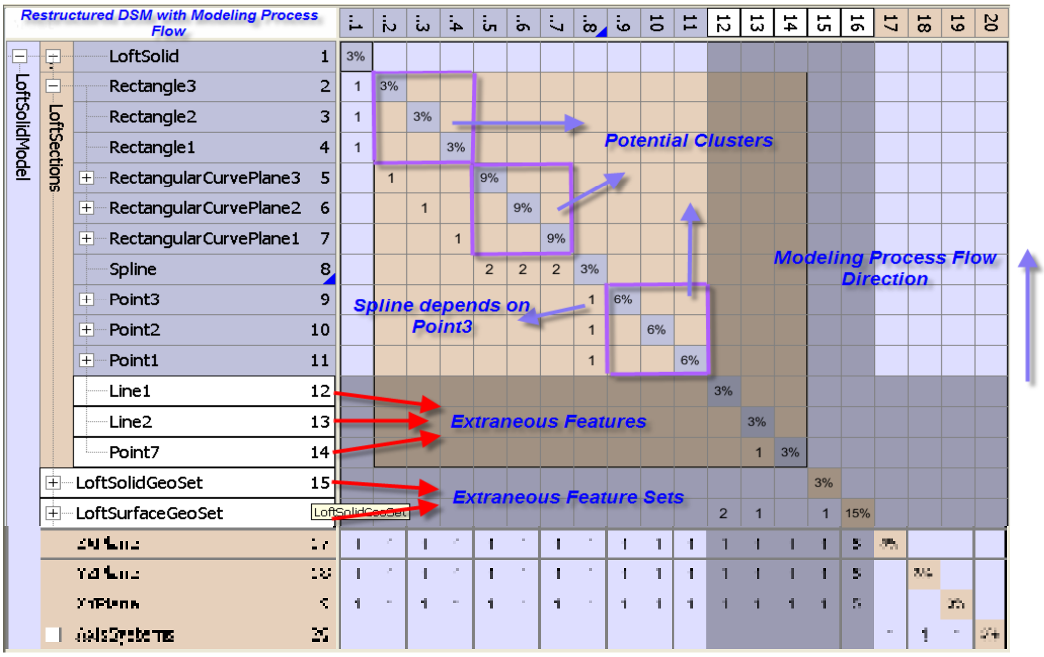
Simple CAD Model
Restructured DSM



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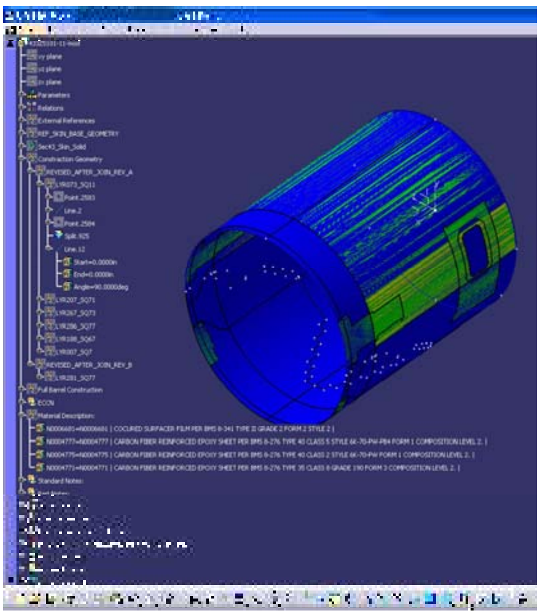
A Complex CAD Model



Airplane Fuselage Section

Size approximately 75 MB

Over 3000 Features, Parameters & Rules

Significantly more topological objects (edge, face etc.)

Nested Structure

Complex Interdependencies

Redundant and Extraneous features

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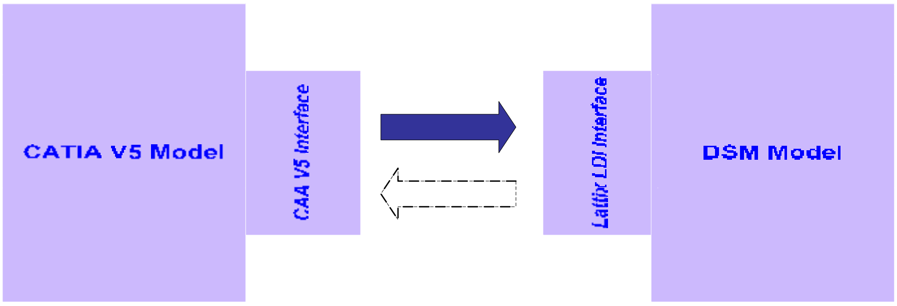
DSM from Complex CAD Model: Challenges

- Impossible to manually create a DSM for a Large and Complex CAD Models
- Requires software tools that can automatically generate DSM from CAD Model
- Requires programmable access to CAD Model as well as the DSM Model
- Needs a thorough knowledge of CAD Architectures



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Benefits of DSM Analysis

- Documents the overall design and geometry modelling process
- Captures design history along with parametric representation of the design process
- Captures parameter and feature dependencies
- Identifies redundant and extraneous features, parts and parameters
- Helps create design modeling clusters
- Enhances design process reuse
- Helps reduce the size and complexity of the CAD model
- Aids in better visualization of the Model structure

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Summary

- Proposal to apply DSM techniques to analyze, understand and restructure complex CAD models
- CAD System used is CATIA V5 but the idea can be applied to other systems
- Sample DSM is created manually for a simple CAD Model
- For large and complex CAD Models an automated way to create DSM needs to be developed
- DSM analysis can help extract the essence of the CAD modeling process
- Future work can explore the possibility of generating CAD Models by reverse engineering DSM models
- And also the research the potential of using DSM Model as a neutral representation for CAD data exchange