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Techniques and Tools for Product-Specific Analysis Templates

Towards Enhanced CAD-CAE Interoperability for Simulation-Based Design and Related Topics

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Abstract

Design engineers are becoming increasingly aware of "analysis template" pockets that exist in their product domain. For example, thermal resistance and interconnect reliability analysis are common templates for electronic chip packages, while tire-roadway templates exist to verify handling, durability, and slip requirements. Such templates may be captured as paper-based notes and design standards, as well as loosely structured spreadsheets and electronic workbooks. Often, however, they are not articulated in any persistent form.

Some CAD/E software vendors are offering pre-packaged analysis template catalogs like the above; however, they are typically dependent on a specific toolset and do not present design-analysis idealization associativity to the user. Thus, it is difficult to adapt, extend, or transfer analysis template knowledge. As noted in places like the 2001 International Technology Roadmap for Semiconductors (ITRS), domain- and tool-independent techniques and related standards are necessary.

This paper overviews infrastructure needs and emerging analysis template theory and methodology that addresses such issues. Patterns that naturally exist in between traditional CAD and CAE models are summarized, along with their embodiment in a knowledge representation known as constrained objects. Industrial applications for airframe structural analysis, circuit board thermomechanical analysis, and chip package thermal resistance analysis are noted.

This approach enhances knowledge capture, modularity, and reusability, as well as improves automation (e.g., decreasing total simulation cycle time by 75%). The object patterns also identify where best to apply information technologies like STEP, XML, CORBA/SOAP, and web services. We believe further benefits are possible if these patterns are combined with other efforts to enable ubiquitous analysis template technology. Trends and needs towards this end are discussed, including analogies with electronics like JEDEC package standards and mechanical subsystems.

Nomenclature

ABB	analysis building block
API	application programming interface
APM	analyzable product model
BGA	ball grid array
CBAM	context-based analysis model
COB	constrained object
CORBA	common object request broker architecture
COTS	commercial-off-the-shelf
DR&O	design requirements and objectives
EJB	enterprise JavaBean
J2EE	Java 2 Enterprise Edition
KBE	knowledge-based engineering
MDA	Model-Driven Architecture
MRA	multi-representation architecture
OMA	Object Management Architecture
OMG	Object Mgt. Group, www.omg.com
PDM	product data management
SMM	solution method model

1 Context

The 2001 International Technology Roadmap for Semiconductors (ITRS)[1] identifies "Difficult Challenges" like the following for Design Technology and for Modeling and Simulation:

> **Design sharing and reuse:** *Tool interoperability, a standard IC information model, integration of multi-vendor and internal design technology, reduction of integration cost.*
>
> **Software module integration:** *Seamless integration of simulation modules with a focus on interplay and interfacing of modules in order to enhance design effectiveness.*

This paper overviews tools and techniques to achieve reusable, modular "analysis templates" that address these challenges. Such templates behave in an automated plug-and-play manner by connecting detailed designs with idealized analysis models and associated tools. Analysis templates for thermal and thermomechanical behavior are of particular interest to electronic packaging. Here we also include mechanical/structural aspects and aerospace

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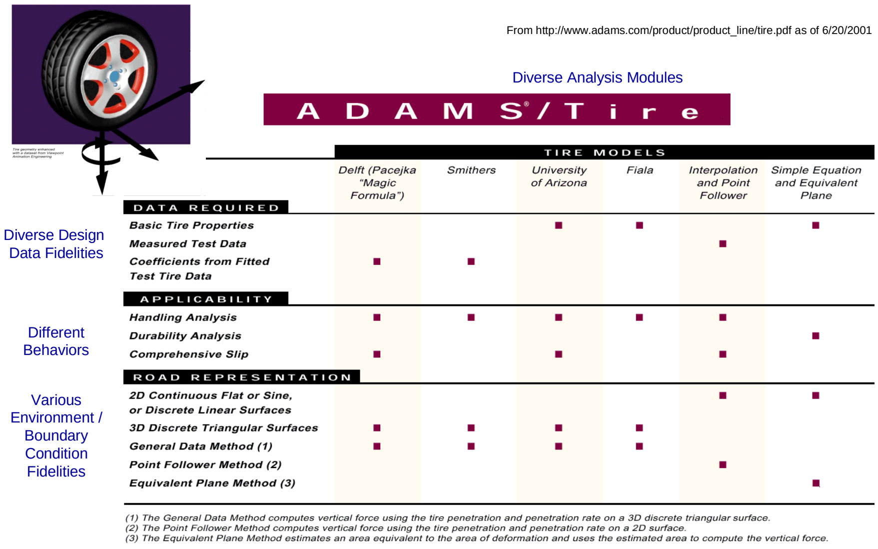
[1] http://public.itrs.net/Files/2001ITRS/Home.htm



From http://www.adams.com/product/product_line/tire.pdf as of 6/20/2001

	TIRE MODELS					
	Delft (Pacejka "Magic Formula")	Smithers	University of Arizona	Fiala	Interpolation and Point Follower	Simple Equation and Equivalent Plane
DATA REQUIRED						
Basic Tire Properties			■	■		■
Measured Test Data					■	
Coefficients from Fitted Test Tire Data	■	■				
APPLICABILITY						
Handling Analysis	■	■	■	■	■	
Durability Analysis						■
Comprehensive Slip	■		■		■	
ROAD REPRESENTATION						
2D Continuous Flat or Sine, or Discrete Linear Surfaces					■	■
3D Discrete Triangular Surfaces	■	■	■	■		
General Data Method (1)	■	■	■	■		
Point Follower Method (2)					■	
Equivalent Plane Method (3)						■

(1) The General Data Method computes vertical force using the tire penetration and penetration rate on a 3D discrete triangular surface.
(2) The Point Follower Method computes vertical force using the tire penetration and penetration rate on a 2D surface.
(3) The Equivalent Plane Method estimates an area equivalent to the area of deformation and uses the estimated area to compute the vertical force.

Figure 1 - An analysis module catalog: tire-roadway interaction on full-vehicle performance

industry experiences in order to leverage general techniques where feasible.

First we overview existing tools and trends, and then we highlight techniques to address identified gaps. Concluding sections discuss technical and philosophical advancements needed to increase model interoperability.

2 Commercial Tools & Techniques

In June 2001 we surveyed current releases of several commercial-off-the-shelf (COTS) tools and techniques. We focused on gauging recent advances in analysis templates and related infrastructure. This section overviews those preliminary findings.

2.1 COTS Tool Progress

More CAD and CAE tool **vendors** are mentioning **interoperability** as a need and/or capability that they have or will have (e.g, Mechanical Dynamics). There are two promising aspects:

1) *Middleware-oriented programmatic interfaces.* For example, MSC Patran.Server (for CORBA), Mathematica Jlink (a Java-based API), Abaqus with a Python API, and CADScript (a Python-based multi-CAD API).
2) *Web-oriented CAD and CAE capabilities.* For example, webMathematica; Internet-based "rental" and usage of solvers from Ansys and MSC; collaboration services like Alibre and CoCreate; web-based visualization toolkits like VizStream.

OMG, J2EE, and .NET-compliant interfaces are also a trend. However, the extent these exist in end user-oriented CAx tools and to what degree these are being used in industry is not clear.

The need for better CAD-CAE integration is more visible and **product-specific analysis tools** (vertical applications with analysis template catalogs) are becoming more prevalent (e.g., tire traction analysis catalogs by Mechanical Dynamics, forging analysis tools by MSC, and electronic chip package tools by Optimal and Fluent). Figure 1 illustrates idealization variety and other dimensions of diversity often present in such catalogs.

Vendors are providing tools for **automated FEA model creation** in the **basic cases** where the same/very similar mechanical part CAD geometry is used as the basis for the mesh model (e.g., CATIA v5 and Ansys DesignSpace).

2.2 COTS Tool Gaps & Issues

While the above progress is encouraging, gaps that expose deeper issues remain. For example, **no vendor-independent analysis template methodology** is evident that supports the **diversity** needed for complex engineering environments. Vendors justifiably tend to focus on their core areas such as geometric shape representation (for CAD) and solvers/pre/post-processors (for CAE) and add analysis templates on top of that. Overall **information theory and abstractions** are lacking with respect to analysis templates.

Additionally, **standards-based modularity and reusability is limited** (natural groupings are not well-defined, and template knowledge is hidden and/or held captive in implementation details).

- The current state is analogous to manufacturing prior to Henry Ford's usage of standardized and interchangeable parts.[2] Tool integration and template environments are tailor-made from semi-custom pieces.[3]
- Some approaches would be better broken into several smaller pieces to enhance reusability. For example, imagine the issues if a car radiator, engine, and transmission were all fabricated from one piece of steel. Instead, these functional units have evolved over time as separate pieces. This naturally decomposes the problem and partitions engineering responsibilities, making manufacture and repair more modular, and allowing the same part to be used on different types of cars (thus, gaining greater economies of scale as well).

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[2] http://www.hfmgv.org/exhibits/hf/

[3] Analysis integration toolkits are also appearing (notably Ansys AI*Workbench and MSC Acumen). However, we had insufficient information during our survey to review them.

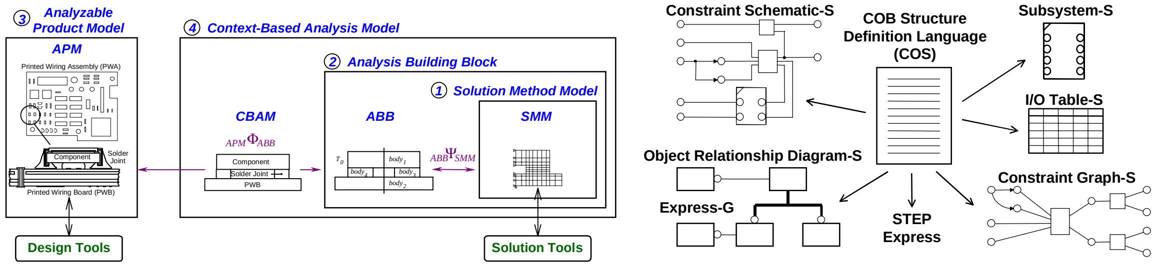

Figure 2 - Multi-representation architecture (MRA) and constrained object (COB) representation for analysis templates

- Similar decompositions and subsystem abstractions are needed for CAD-CAE integration.

The analysis template-like aspects that do exist (e.g., inside TKSolver) tend toward **transforming existing paper-based approaches** directly into documentation-oriented electronic forms.

- While this approach may be more familiar to end users in the near-term, it is analogous to the early days of CAD, which tended to automate 2D drafting rather than deal with richer concepts like 3D solid modeling and features with parametric relations.
- As with 2D CAD, such approaches will help with surface issues but will likely **fail to address deeper needs** in an effective way (e.g. capture of analysis intent and fine-grained design associativity).

Ironically, the noted advances in automeshing and templates tend to mask idealizations and cause some people to think no idealizations are occurring.[4] In reality, aspects like material models, loads, and inter-body boundary conditions inherently involve idealization decisions, even if detailed CAD design geometry is used as-is in a CAE model.

The product-specific analysis tools tend to have **inflexible/inextensible** highly tailored CAD-CAE interfaces (e.g., they often do not give users the option to choose or define different fidelities of idealization).

While some tools are becoming more object-oriented and parametric (e.g., feature-based CAD systems like CATIA v5), often their relations are **uni-directional** and **not fully object-oriented**. This limitation hinders use in knowledge-based engineering (KBE) applications like analysis templates.

3 An Emerging Methodology

3.1 Overview

This section summarizes an emerging analysis template methodology and compares it with the preceding COTS capabilities.

The multi-representation architecture (MRA) in Figure 1 is the conceptual foundation of an X-analysis integration (XAI)[5] methodology based on object-oriented patterns that naturally exist in engineering analysis processes [Peak, 2000, 2001]. It is particularly aimed at design-analysis integration in CAD/CAE environments with high diversity (e.g., diversity of parts, analysis discipline, analysis idealization fidelity, design tools, and analysis tools) and where explicit design-analysis associativity is important (e.g., for automation, knowledge capture, and auditing). In this context, analysis means simulating the physical behavior of a part or system (e.g., determining the stress in a circuit board solder joint).

The constrained object (COB) knowledge representation captures engineering semantics in a modular, reusable manner due to its object-oriented non-causal nature. COBs support the MRA to address the specific needs of engineering analysis integration for simulation-based engineering (SBE), including virtual prototyping, KBE, and CAD-CAE interoperability.

Analysis integration applications of these capabilities include support for design synthesis (sizing) and design verification (analysis), and implementation of MRA concepts as four main types of COBs:

- *Analyzable product models (APMs):* Include multi-fidelity idealizations and multi-source design data coordination.
- *Context-based analysis models (CBAMs*), a.k.a. analysis modules/templates: Contain idealization decisions inside CAD-CAE associativity relations.
- *Analysis building blocks (ABBs):* Represent product-independent analysis concepts as reusable, modular, tool-independent objects.
- *Solution method modules (SMMs):* Support white box reuse of existing tools (e.g., FEA tools and in-house codes). Automatic interactions occur through native command lines or APIs, and/or APIs based on standards like CORBA, Java RMI, SOAP, etc.

Gaps like those in Section 2.2 are the fundamental drivers behind the MRA. Given the expanse between traditional CAD and CAE tools, modularity necessitates having four patterns/representations above. Just as a type of shock absorber can be used on many different types of cars, a given SMM type (e.g., an Ansys FEA SMM) can be used by many types of ABBs; a given ABB can be used by many CBAMs; and so on.

Industrial applications include airframe structural analysis, PWA-B thermomechanical analysis, and electronic packaging thermal resistance analysis and

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[4] See Gordon’s “An Analyst's View: STEP-enabled CAD-CAE Integration” 2001 NASA STEP for Aerospace Workshop. *http://step.jpl.nasa.gov/*

[5] X = design, mfg., sustainment, and other lifecycle phases.

thermomechanical analysis. Results include decreasing total simulation cycle time by 75% [Matsuki *et al.* 2001, Peak *et al.* 2001] and leveraging the richness of an ISO 10303 standard product model: www.ap210.org

3.2 Comparisons & Implications

Table 1 summarizes and compares several types of COTS systems relative to the key features of the MRA/COB-based analysis template methodology. It also identifies generic IT and engineering-oriented frameworks that can benefit these capabilities.

Overall, our approach has been to focus on the **methodology** and **architecture/abstractions** needed for analysis templates. Existing COTS capabilities are leveraged wherever feasible, and new concepts like COBs and CBAMs are demonstrated in a toolkit denoted *XaiTools*[6]. For example, we use COTS FEA and math solvers rather than re-inventing those capabilities; yet MRA/COBs now wrap them in their richer context (including capturing analysis decisions, idealization knowledge and design associativity).

Thus, the MRA begins to identify CAD-CAE modularity breakpoints and the existence and functionality of new subsystems. Its shows where existing tools and methods fit and how their interfaces can be enhanced for effective interoperability. For example, APMs expand the role of traditional CAD to include a variety of operations for idealizations. SMMs do a similar thing for traditional CAE. In between, CBAMs and ABBs clarify the opportunity for whole new classes of models and tools (e.g., *Modelica* for ABBs, www.modelica.org).

4 Discussion & Recommendations

The above highlights how an analysis template theory and methodology is emerging in the form of constrained objects (COBs) and the multi-representation architecture (MRA). This approach is aimed at helping organizations envision and implement next-generation engineering environments by providing the necessary conceptual underpinnings.[7]

However, by itself analysis template theory is not enough. Where does the industry need to go from here? The answer may be contained in a similar question: How can CAD/CAE/CAx environments become more like electronics packaging (with its well-known levels of packaging and decomposition methods)? "Interoperability" in today's engineering environments is as if there were few package standards like those by JEDEC: each "component supplier" is effectively requiring their customers to create a new "footprint" and/or "manufacturing process" to accommodate their "component".

Using the above and other activities[8] as starting points, we recommend the following collaborative tasks:

- Identify other abstract and concrete CAD-CAE integration subsystems and their interactions (determine *what* needs to be standardized).
- Do this at a meta-level as well: define and determine what architectures (collections of appropriate subsystems and interfaces) are sufficient for different classes of problems and organizations.
- Define specific roadmaps for each subsystem and its functional elements.
- Define tasks to move along these roadmaps: identify how existing and in-process standards can be used; determine what extended/new standards and techniques are needed. Leverage work from other domains like aerospace[9] and technologies with the breadth and depth like ISO STEP.[10]

The potential is great. Allen and Sriram [2001] and [Shapiro and Varian, 1999] note the innovative power of standardization and provide stimulating examples. Yet they also warn of the challenges:

> *The benefits from having a robust set of component parts can hardly be overestimated, as they provide the basic infrastructure for innovation. But, as we said earlier, standardization is hard, both from the engineering viewpoint of design, and from the economic point of aligning incentives.*

Further progress will require an awareness of root technical issues like this paper identifies. Yet that alone is insufficient: a new level of international multidisciplinary collaboration, openness, and commitment is needed to overcome the ITRS "Difficult Challenges" noted above.

Acknowledgments

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[6] *XaiTools* is but one potential implementation of the MRA/COB-based analysis template methodology, just as a particular vendor's FEA tool is one implementation of broader FEA concepts.

[7] Imagine attempting to use FEA effectively without having an established FEA theory. An analysis template theory is within reach that similarly needs to be documented, refined, taught, and understood to enable effective simulation-based design.

[8] See related links at the Engineering Framework Interest Group, http://eislab.gatch.edu/efwig/

[9] See, for example, the list of relevant standards identified for the 2002 NASA-ESA Workshop on Product Data Exchange: http://www.estec.esa.int/conferences/aerospace-pde-2002/

[10] STEP (ISO 10303) is gaining momentum beyond its original MCAD emphasis in areas like electronics (AP210), analysis (AP209), and systems engineering (AP233). See sites like the following:

http://pdesinc.aticorp.org/
http://www.ukceb.org/step/
http://step.nasa.gov/step_info.html

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Table 1 - Comparison of System Emphasis and Capabilities: a. Overall Facets

System ***Facet***	**Analysis Template Systems & CAD-CAE Integration Frameworks**		**PDMs & Generic Frameworks**	**MCAD Systems**	**FEA Systems**	**Math Systems**
Example Techniques & Tools	•MRA/COB-based analysis template technique (example *XaiTools* implementation)	•In-house tools, vendor toolkits, …	•Enovia, Metaphase, … o CAA, Accelis •J2EE, MS .NET, OMG standards (MDA, …)	•CATIA v5, I-DEAS, Pro/E, UG, …	•Abaqus, Ansys, Elfini, Nastran, Patran, …	•MathCAD, Matlab, Mathematica, TKSolver, …
Primary Focus	•Represent declarative analysis templates •Capture analysis knowledge •Support CAD-CAE interoperability (smart glue) •Define natural intermediate object types (abstractions) for enhanced modularity & reusability •Support multiple views (e.g., analysis documentation)	•Represent procedural analysis templates •Include internal solvers •Support documentation generation	•Provide core IT capabilities (engineering-oriented and generic): o Middleware & generic interoperability o Information persistence & archival o Versioning, configuration, & security management	•Represent manufacturable physical geometry •Support assembly and bill of material (BOM) concepts	•Represent FEA models •Solve discretized boundary value problems	•Represent math models •Solve general mathematical relations
Typical Unsupported & Non-Target Capabilities *(beyond usual system focus)*	•Replace COTS solvers and CAE tools •Replace CAD tools •Replace coarse-grained PDM capabilities	• Support diverse CAD-CAE interoperability • Support multi-directionality	• Support fine-grained, multi-fidelity, multi-directional associativity • Support CAD-CAE-specific interoperability	• Represent multi-fidelity idealizations • Support multi-directionality • Support diverse CAE and analysis template links	• Mix with other solution tools (e.g., math tools) • Support diverse product-specific analysis template catalogs • Support diverse fine-grained interoperability with CAD, DR&O, and conditions/loads	• Mix with other solution tools (e.g., FEA tools) • Support interoperability with CAD, DR&O, and conditions/loads

Legend for Table 1b *(continued next page)*

●	Tool/technique typically supports capability well
⦿, ○	Tool/technique typically partially supports capability (more fill = greater support)
-	Tool/technique typically does not supports capability

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[11] See vendor websites and web search engines for items not explicitly referenced. Some references above are available at *http://eislab.gatech.edu/*.

Table 1 (continued) - Comparison of System Emphasis and Capabilities: b. Knowledge Representation & Analysis Template Needs

System **Need**	**Analysis Template & CAD-CAE Integration Systems**		**PDMs & Generic Frameworks**	**MCAD Systems**	**FEA Systems**	**Math Systems**
	MRA/COBs	In house & vendor kits				
Knowledge Representation						
Object-Oriented Constructs	●	-	◉	◉ (feature-oriented trend)	○ (feature-oriented trend)	○
Modularity & reusability	●	○	◉	○	○	○
Encapsulation	●	○	◉	○	○	○
Declarative/Constraint Constructs	● (via COBs)	○	○ (syncing, publish/subscribe)	◉ (geometric constraints)	○ (boundary condition-oriented)	●
Multi-directionality	● (constraint mgt. focus)	-	○ (bi-directional equality)	○ (some yes, some no)	○ (some iterate, but limited I/O directionality options)	● (solver focus; harder to manage)
Multi-fidelity	●	-	-	○ (some do-able - not explicit)	◉ (not explicitly linked to same design model)	○ (not explicitly linked to same design model)
Lexical constraint forms	● (analysis template focus)	◉ (analysis template/doc. focus)	?	○ (scripts; geometry focus)	○	● (math focus)
Graphical constraint views	● (several views to aid human comprehension)	-	?	○ (CATIA parent-child graph)	○	-
Constraint management[12]	●	○	○	○	○	○
Constraint solving	○	◉	○	◉ (geometry focus)	○	● (math focus)
Analysis Template-Specific Aspects						
Template Methodology	●	◉	-	-	○	○
Info. theory & abstractions	●	-	-	-	-	-
Explicit Idealizations & Associativity	●	○ (not explicit)	-	○ (some do-able - not explicit)	○ (some do-able - not explicit)	○ (some do-able - not explicit)
Explicit Analysis Template Patterns	● (abstractions)	○ (mixed together; not explicit)	-	-	-	-
APMs	●	○ (not explicit)	○ (generic tool wrappers)	○ (some do-able - not explicit)	-	-
CBAMs	●	○ (not explicit)	-	-	-	-
ABBs	●	◉ (not explicit)	-	-	○	◉ (some with tool-specific libraries: Easy5, TKSolver, …)
SMMs	●	○ (not explicit)	○ (generic tool wrappers)	-	◉ (feature-oriented trend)	◉ (some: Mathematica, …)
Extensibility[13]	●	○	○	○	○	○

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[12] Constraint management takes advantage of the COB information structure for better processing (e.g, collecting only needed constraints to submit for solving [Wilson, 2000, 2001]).

[13] Extensibility here means the likelihood that other analysis template abstractions and capabilities can be supported by the tool/technique. Such capabilities include life cycle pullable views; DR&O, condition/loads, and inter-analysis integration; and auto/assisted results/assumption-checking.