

Towards Next-Generation Design-for-Manufacturability (DFM) Frameworks for Electronics Product Realization

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Abstract

In the fast paced competitive market of electronic products, the time-to-market and cost hold the key to economic survival. High manufacturability of electronic product designs minimizes lead time and costs. In cooperation with the PDES Inc. [7] Electromechanical Pilot, the CAM-I [11] Simulation for Flexible Manufacturing (SFM) project was initiated amongst Rockwell Collins (RCI), Georgia Institute of Technology (GIT) and University of Illinois at Urbana Champaign (UIUC) out of these needs and the inability of conventional ECAD tools to capture some types of manufacturability constraints.

This paper elucidates the process architecture of a pilot implementation of a DFM Framework (specifically the SFM DFM Framework or SDF), which consists of four key ingredients. The first ingredient is a Design Integrator that acquires product design information from an ECAD tool and in-house sources (each populating a subset of the design) and consolidates them into a STEP AP210 model. The second ingredient is a Rule-based Expert System (initiated at Boeing) that captures the manufacturability constraints as DFM rules and evaluates printed circuit assembly (PCA) designs against them. The third ingredient is a Design View Generator that extracts design information from the AP210 model (first ingredient) and library database and derives a *Kappa* design model for the expert system (second ingredient) to evaluate. The fourth ingredient is the Results Viewer that helps the user browse DFM analysis results and identify design improvement opportunities.

This implementation of the SDF demonstrates the ability to extract PCA design information and build a higher fidelity standards-based design model. Additionally, it also shows the capability of Rule-based Expert Systems to emulate manufacturability checks on product (PCAs in this case) designs as well as increase analysis coverage and reduce human checking time via automation.

Keywords

Simulation for Flexible Manufacturing, Design-for-Manufacturability, AP210, STEP, Framework, Design, Manufacturability, Rule-based Expert System, Printed Circuit Assembly

Nomenclature

AP210: STEP Application Protocol 210 standard for electronics (ISO 10303 - 210)

CAD: Computer-aided Design

CAM-I: Consortium for Advanced Manufacturing - International

ECAD: Electronic Computer-aided Design

DFM: Design-for-Manufacturability

ISO: International Standards Organization

JSDAI: Java-based implementation of Standard Data Access Interface

PCA: Printed Circuit Assembly

PCB: Printed Circuit Board

RDD: Rule Data Dictionary

SBE: Simulation-Based Engineering

SDF: SFM DFM Framework

SFM: Simulation for Flexible Manufacturing

STEP: STandard for the Exchange of Product model data (ISO 10303)

1 A Ground Level Perspective of a DFM Framework

1.1 Motivation for Building a DFM Framework

Design and Manufacturing are key activities in the realization of electronic products. The electronic product realization process has assumed multidisciplinary proportions and hence design and manufacturing activities are no longer independent. There is a need for electronic product designers to collaborate with manufacturers, gain essential knowledge regarding the manufacturing facilities and the processes, and apply this knowledge during the design process. The domain that addresses these issues is "Design for Manufacturability" (DFM).

Manufacturing expertise is enriched with "do's" and "don'ts" of the related processes. The bulk production of electronic products, distributed over several manufacturing facilities, does not make it feasible for manufacturers (experts) to physically guide the design process and hence designers. Moreover, designers are not manufacturing experts themselves and hence their ability to appreciate and entertain manufacturability constraints is limited. With the growing complications in product design, there is a pressing need for a solution beyond a manual check of recommended practices pertaining to manufacturability.

Moreover, enterprises vary in their working strategies. There is a need for customizing sub-systems for an enterprise in a manner that these can be "plug and play"

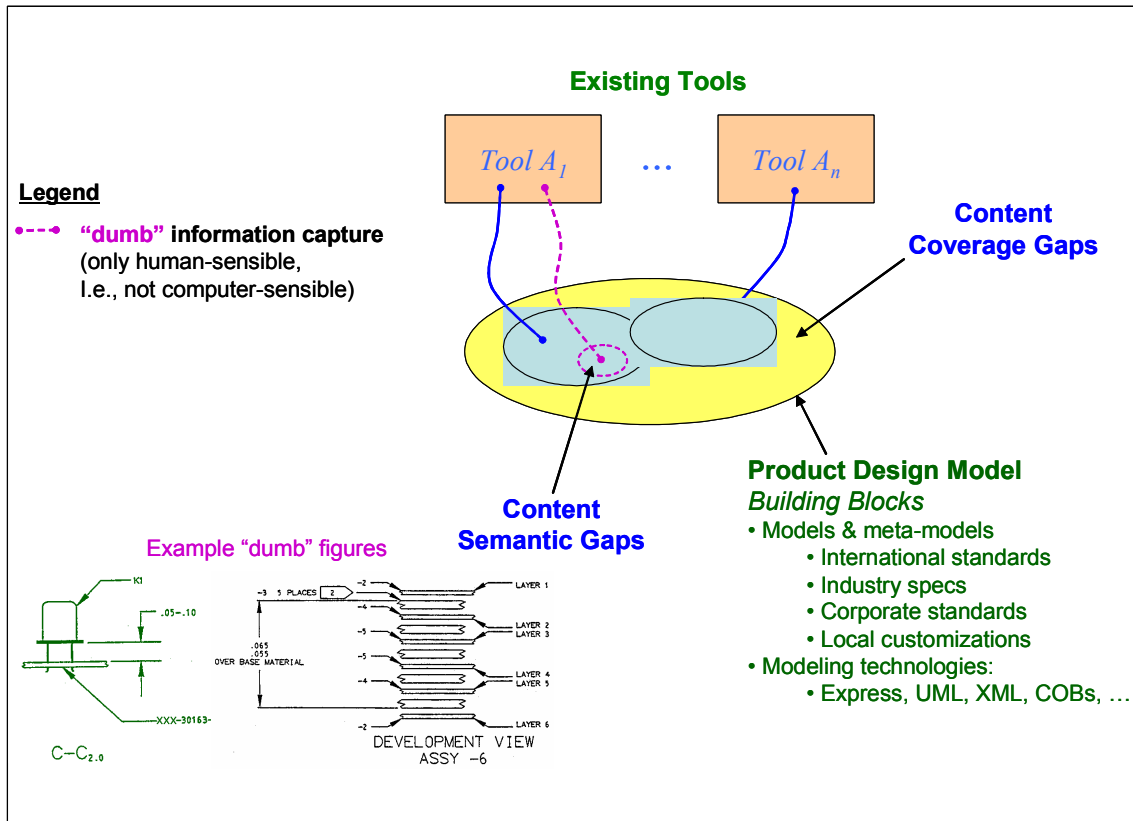


Figure 1: Challenges towards building a rich product design model

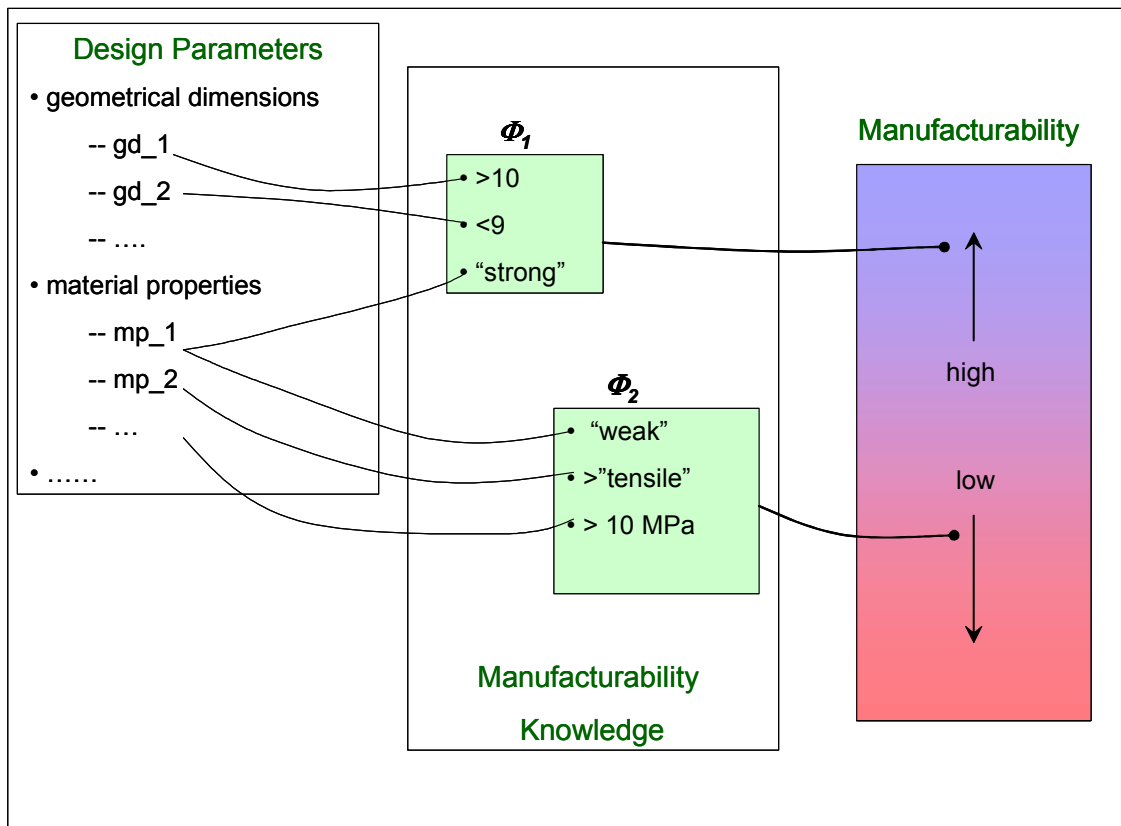


Figure 2: Nature of design-manufacturability associativities

modules in their strategy. In this concern, the importance of a “framework” as a synergistic aggregation of tools has far reaching effects than a “comprehensive tool”.

The ideas expressed above are the key motivations for realizing a DFM Framework to capture manufacturability knowledge and use the same to move towards more robust PCA designs for a fast moving electronics market

1.2 Ingredients of a DFM Framework

The key ingredients of a DFM Framework are outlined below.

1.2.1 Electronics Product Design Model

By Electronics Product Design Model, we refer to the congregation of product design information for electronics products captured along the complete life cycle of the product. As a product moves from its inception as an idea till the time it is manufactured, this blob of information moves from higher to lower abstraction. In the context of simulation-based engineering (SBE), this is the entity being virtually engineered by simulating the processes encountered along its realization timeline.

1.2.2 Facility to Represent Manufacturing Expertise

Knowledge pertaining to manufacturability can be in the form of well documented “rules of thumb” owing to an enterprise’s experience in a given domain. This knowledge can also be in the form of implicit practices adopted by manufacturing experts on a day-to-day basis. A key aspect in a DFM Framework is a facility or a tool that can be used to represent these elements of expertise in a form that product design models may be checked against them.

1.2.3 Ability to Capture Manufacturability Violations

This is a key utility needed by a designer. When a particular design model is checked against the available set of expertise, the designer needs to know how and what features of the design aren’t manufacturable. Future decisions on design variables shall be taken based upon this manufacturability analysis.

1.3 Foreseeing Challenges

One of evident challenges in realizing a DFM Framework is attributed to building the product design model. Figure 1 shows some key issues concerning the same. In a typical enterprise, a reasonable portion of design information may be captured as “dumb figures” as shown in Figure 1. The information in these figures is only human-sensible. Even in a digital format, the information is in pixels or vector graphics (as a part of an image) with no computer-sensible association with the underlying engineering objects and their associated attribute values. The first hurdle is to enrich this to smarter information models where all key design related information is captured.

The second hurdle surfaces when the product design model (central yellow blob in Figure 1) is viewed as a consolidation of information derived from diverse sources

or tools. More often than not, information derived from all tools is insufficient to cover complete information content of the design model. Additionally, since there is no standard terminology used to express design information across different vendors, the problem draws into addressing the evident semantic gaps [1, 2].

The other zone of challenge in realizing a DFM Framework is in capturing manufacturing expertise. The practices adopted by manufacturers may be attributed to limitations of the manufacturing facility and also to experience that has been gained over time. The latter is more cumbersome to capture as it doesn’t have a well-formed structure or a causal hierarchy. Most of it may be “gut-feeling” and implicit practices. Figure 2 shows the nature of associativities, “ Φ ”, between design variables and manufacturability. These associativities may involve fuzzy terminology like “strong” and “weak” etc. along with crisp values of variables and the combination of these values (fuzzy or crisp) that result in “higher” or “lower” manufacturability. Attempts have been made to model “manufacturability” as an objective function which is maximized or minimized pertaining to variation of design variables within specified ranges. However, the problem gets all the more complicated when fuzzy variables have to be addressed. Fuzzy terminology like “small” and “strong” used by manufacturing experts lacks crispness and is open to interpretation.

2 Proposing a Conceptual Architecture for the DFM Framework

Building upon the needs put forth in the previous section, we expand on the ingredients needed to realize a DFM Framework. Figure 3 shows the functional nature of elements within the DFM Framework.

2.1 Design Integrator

As evident from its name, this is a customized tool that derives product design information from diverse sources and consolidates them into a standards-based information model (referring to ISO STEP standards [8] in this paper). The consolidated design model shall henceforth be referred to as a STEP AP210 design model or simply a 210 design model. The 210 design model is a higher fidelity information model as compared to the set of information models it is built from. The word “fidelity” in this context refers to the coverage of information content and the ability to exchange information with both downstream and upstream information models. Being a standards-based model, the 210 design model has a greater allegiance to an increasing number of tools that support these standards.

As shown in Figure 3, the *Design Integrator* extracts information from native ECAD tools, enterprise-specific databases and other auxiliary information sources. Design information in each of these three types of sources is a subset of the complete design model (Figure 1). The number and the nature of these sources of information vary

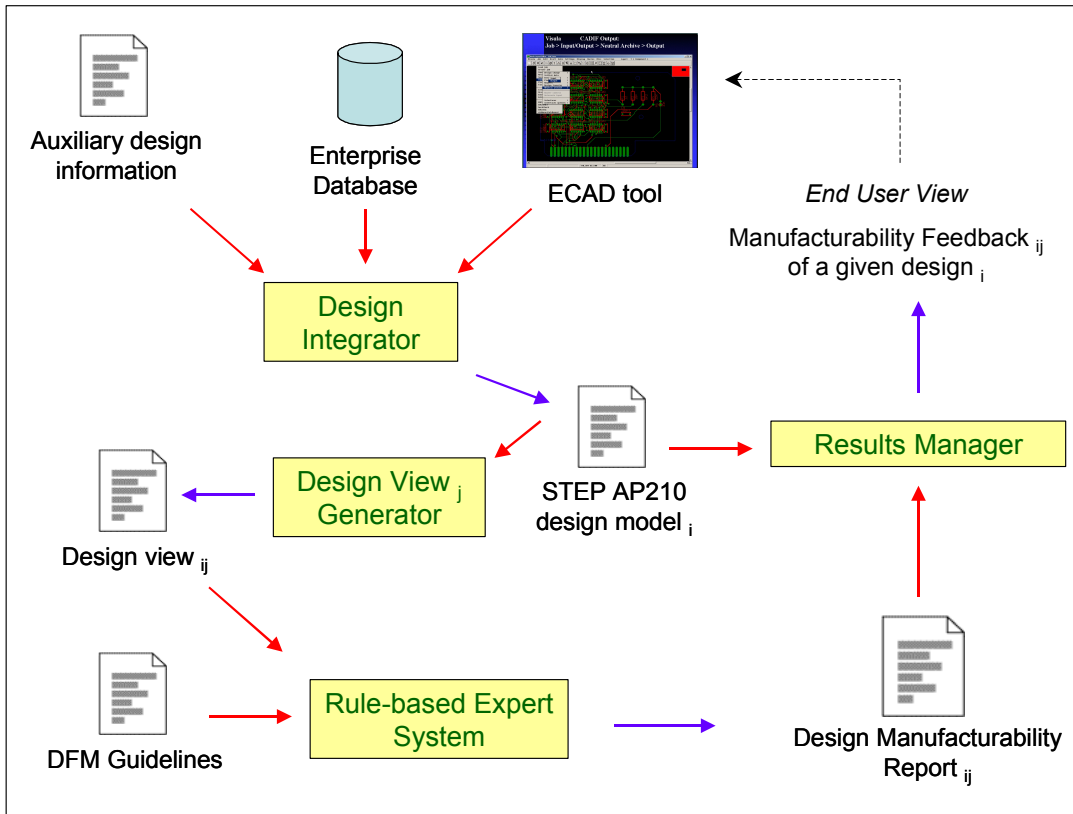


Figure 3: Conceptual Architecture of the DFM Framework

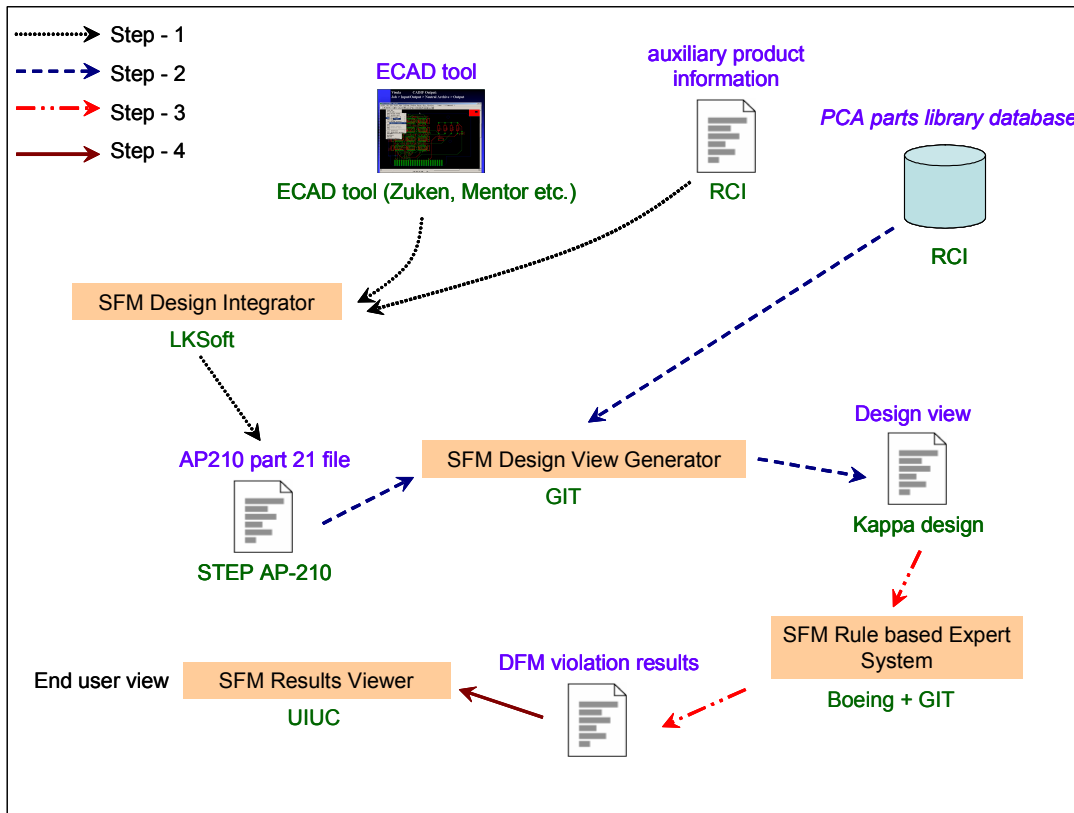


Figure 4: The DFM Framework developed under the SFM project (Phase 1)

from organization to organization and hence a *Design Integrator* is most likely customized to a specific enterprise. However, within a *Design Integrator* there may be reusable components (tools) that can be used across different enterprises, for example, translators to convert design information from a specific ECAD tool to a 210 design model.

2.2 Rule based Expert System

In the words of Professor Feigenbaum (Stanford University), an early pioneer in Expert Systems technology, “An expert system is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution” [4].

A *Rule-based Expert System* is a knowledge-based system (or an expert system) that can represent design manufacturability knowledge (mostly in the form of constraints) as rules [3]. It can, thereby facilitate manufacturability evaluation of design (in this case a 210 design model, as obtained from the *Design Integrator*) subject to these rules.

The use of manufacturing expertise in engineering design is a typical decision making process abound with uncertainties. At any instant during the design process, decisions have to be taken to the best use of available resources and experiential knowledge. Expert Systems allow the emulation of human decision making processes more efficiently as compared to systems supported in procedural paradigms [4]. Contrary to procedural systems (based on computer languages like FORTRAN, C, etc.), Expert Systems are based on expert system programming languages (like PROLOG, Kappa, CLIPS, Jess, etc.) which allow a reasonable separation of knowledge from control. This results in greater modularity and hence superior maintenance of the architecture. As with a realistic learning process, human decisions change over time due to additional knowledge gained. Expert Systems closely emulate this as they allow for the ability to add knowledge to the already existing knowledge repository with minimal or no modification to the way in which this knowledge is used downstream. Moreover, stages in a realistic design and manufacturing process abound with abstraction and uncertainties. Expert Systems are inherently adept at handling these issues and infer from the as-available chunks of knowledge. A typical Expert System allows for the capability to interface with procedural systems to facilitate the optimized use of both worlds.

As shown in Figure 3, the *Manufacturability Knowledge base* is a repository of manufacturability rules, say repository j (constraints and recommended practices). In the context of a DFM Framework, the 210 design model (say design model i) is checked as per the knowledge available from this repository (say repository j) by the *Rule-based Expert System*. For example, some rules might check that fiducials are within a given distance to specific components, whereas others might check distances between fine-pitch features. The *Rule-based Expert System* has an

inference engine that draws inferences from this manufacturability check and generates a *Design Manufacturability Report* ij .

2.3 Design View Generator

The *Rule-based Expert System* needs design information in its native specifications. The 210 design model is a rich holistic model. The *Design View Generator* extracts a view (say Design View ij) in a format sensible to the *Rule-based Expert System* and hence ready to use by the same. This view is derived from design model i to be checked against constraints in knowledge repository j .

2.4 Results Manager

The *Results Manager* uses the *Design Manufacturability Report* ij developed by the *Rule-based Expert System* (210 design model i checked against the constraints in knowledge repository j) It parses this report and generates a graphical view of the 210 design model and associated manufacturability violations (Manufacturability Feedback ij).

3 Development of the SFM DFM Framework (SDF)

The development of a pilot implementation of the DFM Framework was initiated amongst RCI, GIT and UIUC under the CAM-I Simulation for Flexible Manufacturing project. The first production version of this DFM Framework has been accomplished recently. The key ingredients of the developed Framework, inline with the conceptual architecture discussed above are as under-mentioned. Figure 4 shows the developed architecture of this DFM Framework, henceforth referred to as SFM DFM Framework (SDF).

3.1 SDF Design Integrator

Based upon Design Integrator-related concepts proposed in Section 2.1, the *SDF Design Integrator* consolidates a higher fidelity and a richer AP210 [6, 7, 9] design model as a STEP part 21 file from two information packets. The primary source of PCA design information is the Visula toolkit (ECAD tool) from Zuken [10]. The other packet termed “auxiliary product information” concerns PWB layer specifics and other attributes not managed by Visula. The PCA design information in Visula can be written out to CADIF neutral format. Thereafter, CADIF-sensible design information is used along with the “auxiliary product information”, by the *SDF Design Integrator* to build the 210 design model. The *SDF Design Integrator* is built on the *CADIF-210 Converter* by LKSoft [9]. Figure 5 shows a snapshot of an example 210 design model as viewed in LKSoft [5] STEP Book.-210 browser tool.

3.2 SDF Design View Generator

As shown in Figure 4, the *SDF Design View Generator* uses the 210 design model and the in-house PCA parts library database and builds a design view. This process

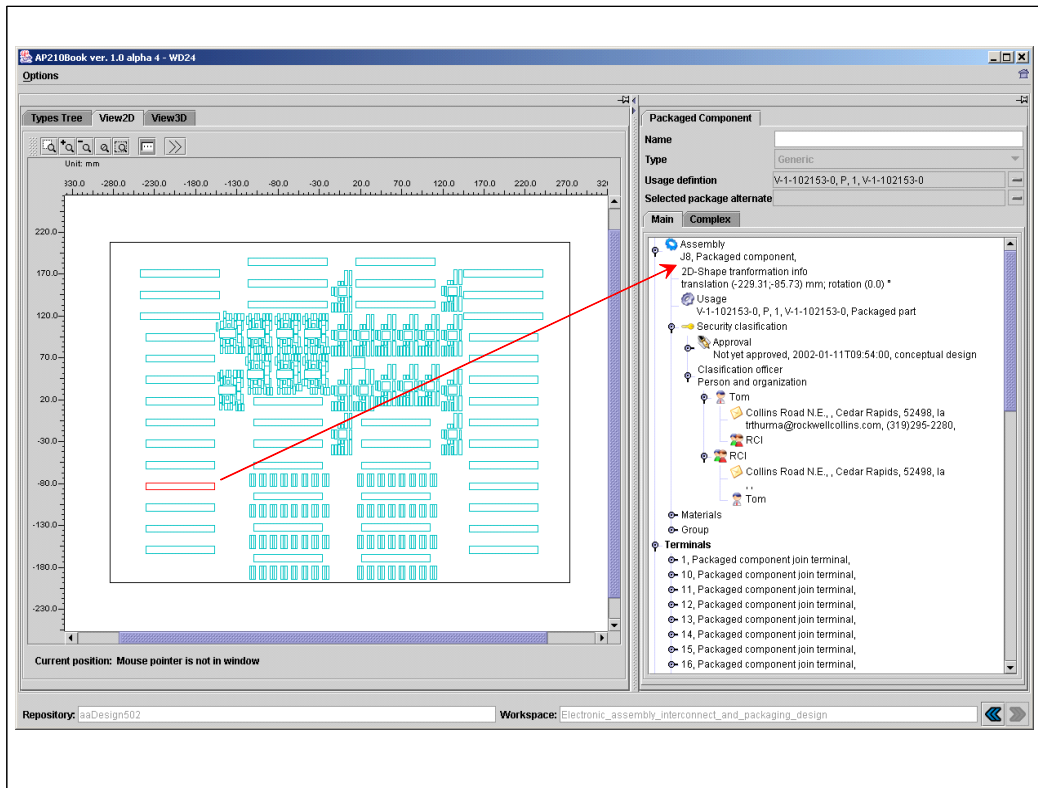


Figure 5: An example 210 design model as viewed in the STEP Book – AP210 Browser (LKSoft)

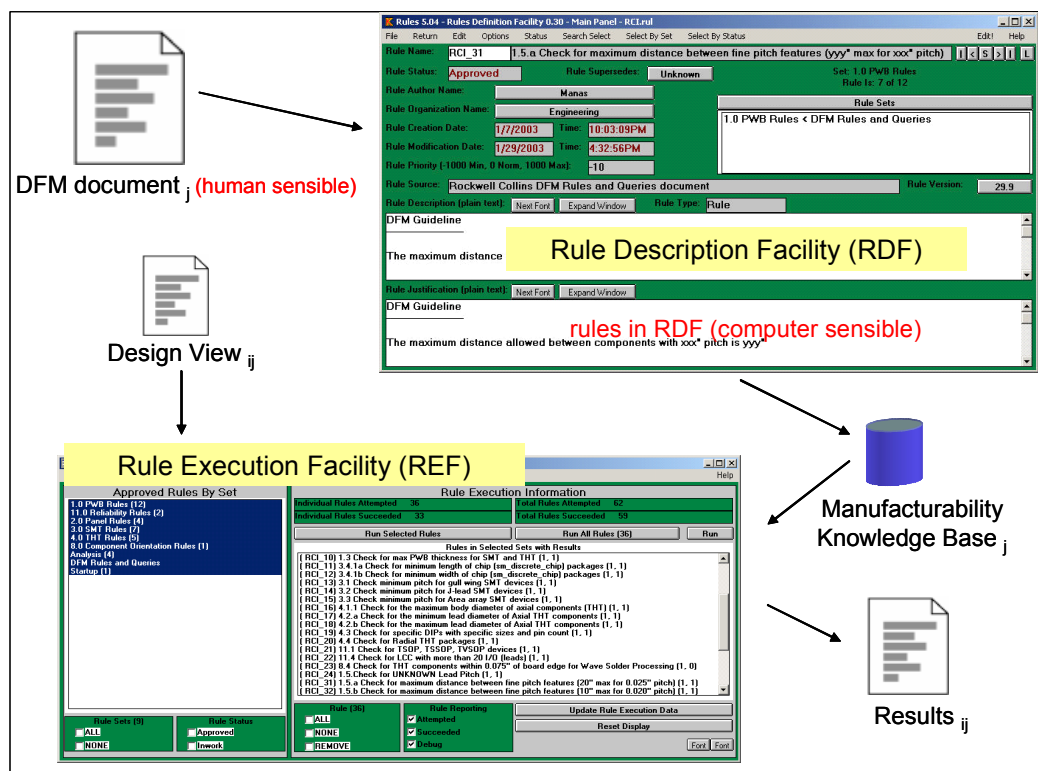


Figure 6: SDF Rule-based Expert System

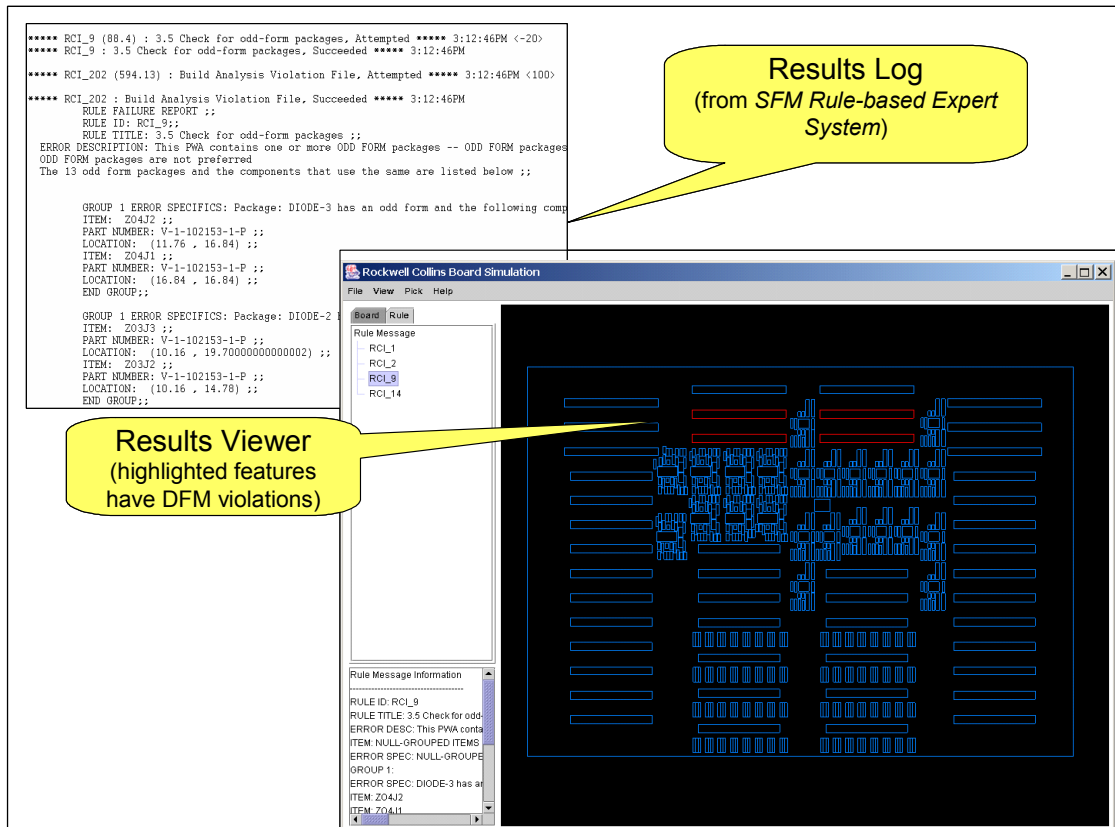


Figure 7: DFM violations as viewed in SDF Results Viewer

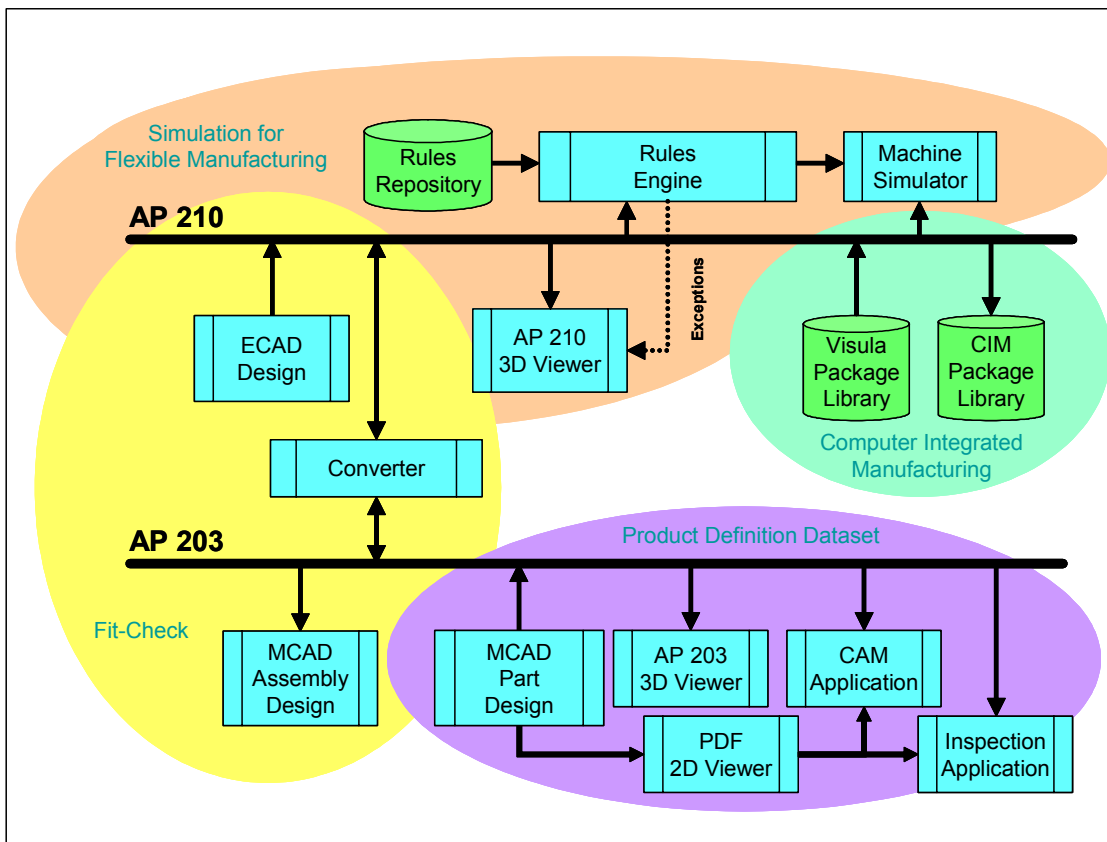


Figure 8: Future Architecture – standards-based (STEP) data bus and repository approach

comprises of two main stages. Firstly, a subset of design information is extracted from the integrated 210 design model. Thereafter, this information subset is written out to a *Kappa* instance file (KAL file) conforming to the *Rule Data Dictionary* (RDD) schema, as discussed in the next section.

The *SDF Design View Generator* uses the PCA parts library database to populate information specifics pertaining to electronic components and packages used in the PCA. This ingredient of the DFM architecture was developed by GIT.

3.3 *SDF Rule-based Expert System*

The basis for the *SDF Rule-based Expert System* was a *Kappa*-based Rules tool (based on the *Kappa* expert system programming language) built by Boeing. During the first development phase of the SFM project, a new manufacturability knowledge base was developed by GIT to be used with this Rules tool. Figure 6 shows details concerning this tool. The Rules tool is comprised of two facilities. They are namely, the Rule Definition Facility (RDF) and the Rule Execution Facility (REF). The RDF provides a graphical interface to develop a knowledge base, which in this case is the set of manufacturability constraints expressed as rules. This set of manufacturability constraints, expressed in a human sensible format, is available from a document furnished by RCI. The REF allows for checking the design model against these rules and thereby generates the violation report.

The design view (say Design View ij), which is an input to this tool, is based on the *Rule Data Dictionary* (RDD) schema. This design view is checked against constraints from the Manufacturability Knowledge Base j and the results of this check are output as Results ij as shown in Figure 6. Specifically, this design view is a conglomerate of instances of the entities defined in the RDD schema. A RDD schema for the PCA design model was developed by GIT. The design file pertaining to this schema is also referred to as the KAL file (based on *Kappa* programming language). It can be thought of as a simplified view (a sub model) of an AP210 model that specifically supports DFM checking. The *SDF Rule-based Expert System* outputs the DFM violations, of the given RDD-based design when checked against the manufacturability knowledge base, as a log file (ASCII text format).

3.4 *SDF Results Viewer*

The *SDF Results Viewer*, developed by UIUC, is a graphical interface tool that highlights the manufacturability violations. Figure 7 shows a snapshot of this tool which is based on the LKSoft JSDAI STEP processing toolkit. The *SDF Results Viewer* parses the violation log output by the *SDF Rule-based Expert System* and uses the 210 design model to display the specific components of the PCA that have violated the manufacturability constraints.

4 Future Work

Figure 8 shows the work-in-progress future architecture of the SDF. It shows the standards-based (AP210 and AP203) information models available in a data bus from which other tools exchange information. This goes back to

answering the challenges highlighted in Figure 1. The standards-based data bus and the associated transactions with different tools are currently file-based. In the future, this data bus shall assume the form a standards-based repository and the transactions associated with the same shall take the form of queries.

Conclusion

This paper puts forth the necessity for a DFM Framework to enhance the manufacturability of printed circuit assembly designs and describes the development of the same under the multi-organization SFM project.

It outlines the basic ingredients needed to build a DFM Framework and highlights underlying challenges. It points towards the inability of conventional design tools to capture design information completely and it also draws attentions towards the associated semantic gaps in a multi-tool collaborative environment. It demonstrates the use of a standards-based information model (STEP AP210) to capture engineering designs that are richer in content and have higher fidelity, as well as to fuse information from disparate sources.

Thereafter, it develops a conceptual architecture of the DFM Framework and proposes the use of a Design Integrator to develop rich 210 design models and a Design View Generator to extract a subset of design information for manufacturability checks. It also proposes the use of a Rule-based Expert System and argues for its usage as compared to systems or tools based on procedural paradigms. It also suggests the use of a Results Viewer to develop end user graphical views of the 210 design model and the associated manufacturability violations.

This paper also describes the development of a pilot DFM Framework (SDF) based on the above principles during the first phase of the CAM-I SFM project.

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See also:

- <http://eislab.gatech.edu/projects/rci-sfm/>
- <http://eislab.gatech.edu/efwig/>