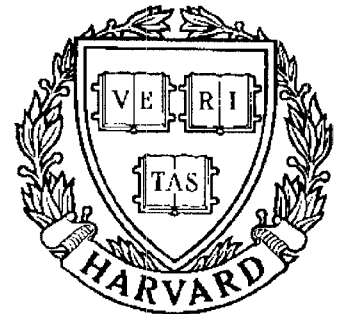


TECHNICAL RESEARCH REPORT



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A PDES Model for Microwave Modules

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A PDES Model for Microwave Modules

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ABSTRACT

This paper presents a novel application of the Layered Electrical Product (LEP) model of the PDES (Product Data Exchange specification using STEP) standard. All three levels of the LEP model are developed for a typical microwave module (MWM). The latter comprises of a component layer, the artwork, an insulation layer and a ground plane, which is a complex mechanical part. The nature of the ground plane necessitated the enhancement of the first level of the model to include three dimensional topological entities. Consequently, although the artwork and insulation layers are represented in two-and-a-half dimensions, (which is common practice in the case of Printed Wiring Boards), the ground plane is modeled using the three-dimensional PDES Geometrical and Topological models and the Form Features model. Level II includes the electrical entities of the MWM. New conventions that are necessary to represent particular features of the MWM have been proposed and applied. Based on the intention of PDES, design information that is closely related to manufacturing concerns has been represented in Level III of the model. Both the proposed structure and the contents of this level for MWMs are presented. Material specifications, mechanical features, design specifications for the manufacture of joins, and others are included. Finally, potential applications of the LEP model and especially of Level III in automated process planning and producibility assessment are discussed.

1. INTRODUCTION

PDES (Product Design Exchange specification using STEP) is the developmental activity in the United States in support of the international standard STEP (Standard for the Exchange of Product Model Data). When fully developed, STEP [1] will be capable of modeling a product through its entire life cycle, starting with the design model on any CAD system. The STEP file for a product will contain its physical description as well as an application specific representation. The physical description is intended to be application independent and could be translated to an application specific representation for manufacturing, process planning, NC code generation, etc.. The product data will be described using reference models defined in formal definition languages. These standardized reference models and the formal definition languages will provide a rigorous framework for the standard.

PDES currently provides three models for an electrical product [1]. The Electrical Functional Model (EFM) describes product functionality and comprises of three parts : functional hierarchy, characteristics and behavior, and logical connectivity [2]. The Layered Electrical Product (LEP) model defines a framework for describing data about an "as-designed" electrical product which can be topologically expressed in terms of layers. It captures complete description of the product, starting with its geometrical and topological attributes, relating them to electrical entities and, finally, mapping them to manufacturing attributes in order to facilitate various manufacturing applications [3]. The Electrical Schematic Model (ESM) represents component parts and their electrical connection. This also includes parts with a mechanical function, e.g., heat sinks, connectors, etc., and details of optical, magnetic or microwave energy transmission.

This paper focuses on the Layered Electrical Product (LEP) model. The original version of the LEP model was developed by the CalPoly Task Team in 1987 [3] to represent printed wiring boards (PWBs). This original model has been adapted and enhanced here to cater for MWMs. It is noted that each layer of a PWB can be topologically modeled in two-dimensions. Consequently, the Topology Information Model (TIM) used in the CalPoly LEP version was capable of representing only two dimensional entities. This is not the case for a MWM, especially due to the ground plane, which is a three dimensional mechanical part and includes features, such as holes, slots, chamfers, cutouts, etc. As a result, the present study uses the full PDES TIM, as well as the Form Features model, to describe the geometry and topology of MWMs. A second critical characteristic is that MWMs typically operate at radio frequencies and, thus, portions of their artwork assume electrical functionality. These portions have to be defined and modeled as distinct entities. Finally, since the manufacturing technology for MWMs is quite different from that of PWBs, new entities have to be defined to represent design-for-manufacture information for the relevant manufacturing technology.

The paper provides an overview of the three levels of the proposed model in section 2. A detailed discussion of the Geometry, Topology & Electrical Translation is presented in section 3. Section 4 proposes a technology specific model of design-for-manufacture information for MWMs. Section 5 discusses potential applications of the proposed model, currently under investigation at the University of Maryland, for the automated extraction of part Group Technology codes, producibility assessment and rough costing estimation. The conclusions of this work are presented in Section 6.

2. OVERVIEW OF THE LEP MODEL

Figure 1 illustrates the architecture of the proposed LEP model for MWMs. According to the CalPoly framework the model includes three levels of abstraction.

The first level decomposes a MWM in layers, each layer defined by the material it bounds. Starting from fundamental geometrical entities such as points and unit vectors, this level is based on higher geometrical and topological entities. In this study, level one is built using the PDES Topology Information Model (TIM) and Form Features Information Model (FFIM). The TIM describes only the boundary representation(B-REP) of the product and excludes all features, such as holes, chamfers, etc., which are included in level three. Level one also describes the concept of 'joins', i.e. the physical connectivity between layer elements. The joins are abstracted as topological edges with vertices representing the process of joining.

Level two is the first application specific translation of the physical description of the product [see Fig 1]. Geometrical and topological entities of level one are translated into the basic elements of level two, i.e. point shapes (pads), graph shapes (traces), and area shapes (ground planes). Higher level entities are defined by pasting together these basic elements. The highest entity of level two is a Layer, which is defined by the material bound. This level also references electronic components (such as capacitors, resistors, etc.) and their location, although the former are to be described in detail by separate PDES models, not included here.

Level three is the second application specific translation of the model [see Fig 1]. It translates both level one and level two entities into design-for-manufacture entities. Although the purpose of this level is consistent with the CalPoly intention, a novel structure is proposed for MWMs. This structure; i)

models the product's features using the Form Feature Information model (FFIM) of PDES [1], ii) integrates the various layers to a single LEP product using the PDES Product Shape Configuration Model (PSCM) [1], iii) describes material attributes using the PDES Material model.[see Fig 1]. Features are modeled as constructive solid geometry (CSG) entities which can be added to or subtracted from the B-REP model of level one. The function of the PSCM is to integrate the B-REPs of the individual layers of the MWM into a single representation for the product to which the form features are appended. The Material model is used to describe the types of material used in different layers of the product, as well as the types of material deposited on the surface of various layers and features, such as passages. Special product design entities required by generative process planning software of a manufacturing facility are also incorporated in this level. The PDES Tolerance model will later be used to specify the design tolerances for each feature as well as for the entire assembly.

3. GEOMETRY, TOPOLOGY & ELECTRICAL ENTITIES

3.1 Level One

This is the most abstract level of the LEP model. It uses the PDES Topological Information Model (TIM) to describe the Boundary Representation (B-REP) of each layer of the MWM substrate. Thus, the substrate is abstractly stripped into topological layers, each made from a unique material. The Layer IDs are assigned in a top-to-bottom manner, starting with the artwork layer at the top. Figure 2 shows a schematic representation of a typical MWM comprising of three layers. The artwork and the insulation layers can be described in two dimensions, since they are identically extendable to the third dimension. Consequently, a two-and-a-half dimensional subset of the PDES TIM is employed to describe them. However, the ground plane is typically a

complex mechanical part and, consequently, is modeled using the full three-dimensional PDES TIM. It is noted that an array of several 2-1/2-D and 3-D layers may be necessary to describe more complex MWM substrates. Although a global coordinate system (GCS) is used in level one, each layer may be considered as an independent topological entity. The origin of the GCS is located at the center of the "bullseye" (i.e. datum point) of the artwork on the top-most layer.

In this study, the PDES TIM has been employed to describe the B-REP for the outer envelope of each layer of the MWM, as well as the geometry and topology of the artwork on the top layer. The features of the substrate, such as holes, chamfers, slots, etc., are not dealt with at this stage and will be described in the proposed level three. Table 1 lists the PDES basic geometrical and topological entities in level one.

The following example illustrates the modeling of the artwork, using the PDES TIM. Figure 3 is a top-view of the artwork of the specific MWM used as a test case throughout this work. Detail A of figure 3 is shown in figure 4. It comprises of two ground planes and part of a trace. Topologically these entities are represented by two faces and a path, namely Face IDs 19, 20 and Path ID 6. According to the PDES TIM, each face is the result of mapping a Path or a Loop onto a previously defined Surface. For example, Face # 19 is formed by a mapping Loop # 19 onto the underlying surface. In turn, a Loop is a closed set of defined Edges or bounded Curve Segments (Curve being a Line, Circle, etc.). In this case, Loop # 19 is composed of Edge # 143, 144, 145, 146 & 147. Each of the five Edges are defined by appropriate Lines and are bounded by start and end Vertices. The direction of each edge is defined using a boolean directional identifier. For example, Line # 143 is bounded by starting Vertex # 156 and ending Vertex # 157. The directional identifier is 'T'(true) in this case, since

Line # 143 and the corresponding Edge # 143 are in the same direction. Detail 'B' in figure 4(b) illustrates the description of the 'intra-layer join' between Edge # 142, which defines the centerline of the trace, and Loop # 19, which represents the boundary of the ground plane. The join is represented by Vertex # 155. It is noted that an 'inter-layer' join between two or more layers is abstracted by a topological Edge and the process of joining is again represented by the corresponding Vertices.

The new conventions introduced in LEP level one to facilitate modeling of MWMs are listed below:

- i) A single global coordinate system is proposed for the entire part with the origin located at the 'bullseye' of the artwork layer;
- ii) The artwork and the insulation layers are modeled using a two-and-a-half dimensional subset of the PDES TIM, whereas the ground plane is modeled using the three-dimensional PDES TIM;
- iii) Artwork patterns, such as traces with a constant width, can be either modeled as paths (i.e. open-ended collection of edges) or as a closed set of edges forming a loop and, subsequently, a face. It is proposed that patterns with a width less than 0.1 inches be modeled as paths, while wider traces be modeled as faces. It is noted that there exists a need to define an aspect ratio (length/width) to distinguish between traces and ground planes, in order to clearly specify the geometrical and topological modeling entities. In some cases the width of a trace may vary along its length. Such traces have been modeled as faces;
- iv) Portions of the artwork that become functional at radio frequencies are rearranged, such that they can be modeled as a single topological unit. In the case of a splitter-combiner unit for example, some traces had to be artificially

segmented, such that the artwork of the entire unit could be defined by two loops. [see Fig.]

3.2 Level Two

The physical description in level one has no electrical significance. Some topological entities of this level are translated to electrical entities in level two. The CalPoly model, although originally proposed for PWBs, was found to fully meet the needs of MWMs.

The entities of level two, proposed by the CalPoly team, are listed in table 2. The basic elements of level two are point shapes (pads), graph shapes (traces) and area shapes (ground planes) which were first introduced in the CalPoly model. The basic translation in this model occurs from the topological entities of Loop, Path and Face to Closed Graph Shape, Open Graph Shape and Area Shape, respectively. These basic elements are used to define more complex entities, which are upgraded to finally define the layer which is the highest entity of level two [see Fig. 5].

The artwork on layer one can be divided on the basis of material presence into two types. Areas that include elements, such as traces, ground planes and pads which are made from the same material are classified as Layer Element Subregions. Areas that do not include such elements, but are still inside the outermost material bound, as well as icons, text and keep-out areas, are classified as Logical Subregions. The intra and inter-layer joins, as well as component lead joins are Layer Element Subregions.

A useful entity defined in the CalPoly model is the Point Shape and is used here to represent pads, fine tuning stubs ('chicken dots'), etc. These objects are topologically identical and appear repetitively at various locations on the artwork. Hence, their geometry and topology are modeled once for each type separately in level one. This topological description is then referenced in

level two, using a unique locating vertex and a shape aspect that describes the relative orientation of the Point Shape in the GCS.

Components that will ultimately be described in the PDES CAD component library are referenced in this level and their location is described by a Vertex using an intersection entity called Component Lead Vertex. The join of a Component Lead with the substrate is modeled topologically as a Vertex and is represented in level two as a Component Lead Join.

The highest entity of this level is the Layered Electrical Product that integrates the abstractly defined material bound Layers into a single substrate. The sequence in which the Layers appear in the substrate are modeled by the entity Layer Sequence.

To illustrate some aspects of level two of the LEP model, the example of detail 'A' [see Fig. 3] from the test part is translated to level two. The two Faces # 19 and 20 [see Fig. 4] are translated into Area Shapes # 19 and 20 of figure 5, while Path # 6 is translated to an Open Graph Shape # 36 [see Fig. 5]. The various instances of shapes are mapped into the entity Shape. Shape is referenced by an intersection entity, Layer Element Shape, which is finally mapped into a higher level entity called Layer Element, such as LE # 36, 69 and 70. The latter are upgraded to Layer Element Subregions (LES) # 36, 69 & 70 [see Fig. 5(b)]. The Intra-Layer Join represented by Vertex # 155 is referenced by Element Join Subregion (EJS) # 17.

4. PROPOSED LEVEL THREE : DESIGN FOR MANUFACTURE DATA

4.1 Overview

The objective of level three is to capture design information to be used by manufacturing applications, such as process planning. Thus, it provides a manufacturing engineer's view of the design. This is the second application

specific translation of the physical description in level one and the electrical description in level two.

The proposed level three for MWMs integrates the following PDES models :

- i) Form Features Information Model (FFIM),
- ii) Product Shape Configuration Model (PSCM), and
- iii) Material models.

Entities from level three of the original CalPoly LEP for PWBs that are applicable to MWMs, have also been retained. Furthermore, some new entities that address process planning concerns particular to MWMs, are introduced [Fig. 6]. Level three also references the Electrical Functional Model and the PDES CAD Components Library, which is currently under development by PDES Inc.

The individual layers of the MWM, described in levels one and two, are integrated into a single assembly using the PSCM. The appropriate features of the assembly are defined using Constructive Solid Geometry in the FFIM. They are then integrated with the B-REP of the assembly of layers to provide the complete substrate description. This rationale mirrors the manufacturing procedure typically followed for MWMs, i.e. the individual layers are first assembled, the artwork etched and finally features are manufactured by mechanical processes.

A typical three layered MWM [Fig. 2] is described using the Assembly Component Usage entity of the Product Structure Configuration Model (PSCM). This entity defines the parent-child relationship between the integrated assembly and its constituent layers. The features of the MWM, which are described by the Form Features Information Model, are referenced by the Configuration Item entity of PSCM. The features of the MWM are

described as swept volumes using CSG in the FFIM. This model exploits the concept of symmetry to define axisymmetric features. Using an intersection entity, the features are upgraded and integrated with the layer assembly. The location and orientation of these features is specified through geometrical entities of level one, which are referenced by FFIM entities. Figure 7 illustrates the use of FFIM by a simple example. A passage is modeled by the feature "hole" mapped onto the substrate assembly [Fig. 7]. The location of the center is defined by P# 351 of the MWM, and the orientation of the hole in the GCS is described by defining a relative orientation of the local co-ordinate system with respect to GCS, using an Axis-2 placement from level one [1]. This information is then referenced into entities of level three where the hole is defined as a constant diameter axisymmetric feature sweep. This defines the profile of the hole to be swept located at P# 351. The length and size, along the local z-axis, of the profile to be swept is defined as 'Sweep Size', or the circumference of the circular profile at the base of the hole, and the 'Sweep Length', or the height of the cylinder. The relative location of the hole in the B-Rep of the assembly is defined by specifying the entry and exit faces for the solid volume to be removed, in terms of the Bounding Faces for the hole.

The Material model specifies the properties of the material to be deposited on the layers, as well as the information about the holes functioning as electrical connections. The Tolerance model will be used to prescribe the tolerances for features, including positional, dimensional, cylindricity tolerances. The further integration of the PDES Tolerance model with the FFIM and other models in level three, is currently investigated.

Level three will be interfaced with the PDES CAD Components Library and the Electrical Functional model(EFM). The first provides information on component occurrence, such as component geometry and location. The EFM

provides an electrical representation to the physical description of joins and passages in terms of 'Electrical Logical Links'.

4.2 Structure and Entities of the Proposed Level Three

Figure 6 presents the structure of the proposed level three and its entities in an IDEF-1X representation. The product is characterized by the type of its insulation layer, represented in the entity Substrate. The attribute Substrate Type is used here to describe the presence of one or more insulation layers; for example ceramic, duroid, or a combination of the two. The entity Microwave Module references the Substrate Type and relates it to the LEP Item ID and the Production Plan ID for the MWM under consideration. The test specifications for the product are incorporated in the Test Coupon entity that relates this information to the LEP Item ID and the Production Plan ID.

The components of the MWM, which will be fully described in the PDES CAD Components library, are referenced by level three through the entity Component Type [see Fig. 6]. This entity relates the Reference Designator (Ref Des) from the entity Component of the components library, to the LEP Item ID. Its attributes include: Component Description, Component Type (eg. die, multi-lead planar or thru hole component), Attachment Technique Type and number of Leads and Lead Pitch. The Attachment Technique Type is used to describe the process of attaching the component to the substrate. The component may be solder surface mounted or solder 'thru-hole' mounted, which may be supported by a mounting block or adhesives.

The Attachment entity is analogous to the Component Type entity for electrical components. It, however, represents information on the set of non-electrical or mechanical parts present on the substrate, such as roll pins, ground pins, etc. It includes the LEP Item ID, Part # (to distinguish between

repeated occurrences of the same mechanical part), Attachment Description and the Attachment Technique Type.

Holes for 'thru-hole' mounting of electronic components and/or mechanical parts are mapped from the FFIM into Level three as Passages [Fig. 6]. The Passage entity associates the Form Feature ID with the LEP Item ID, and includes the attributes - Production Plan ID and Passage Usage. The latter describes three well-defined functional usages for a passage, i.e., a component lead or mechanical lead passage, inter layer join, and electrically plated passage. Those passages that are plated for electrical connectivity, are defined by the entity Electrically Plated Passage. The Passage Deposition entity references the Material to be deposited from the PDES Material model and relates it to the Passage entity, thereby enunciating Passage Deposition Specifications and Passage Deposition Thickness. LEP Item Id, Production Plan ID and Form Feature ID are the other attributes for this entity. In the case of multiple depositions, the preceding and succeeding depositions are specified in the entity Passage Deposition Sequence. Electrically Plated Passages can be further classified as Vias. The Component Lead Passage is employed to carry single or multiple component leads of electrical components. Passages for carrying single or multiple leads of a mechanical part are specified by the entity Mechanical Lead Passage.

The Layer to Layer Joins, previously modeled as Paths in Level Two, are upgraded here to a Layer to Layer Join String that instantiates the use of passages as an electrical connection.

The deposition sequence for the substrate is specified by the Layer Deposition entity, which references the Layer entity from Level Two, and the Material entity to provide the Deposition Specification, Deposition Thickness,

LEP Item ID, Product Item Version ID, the Deposited Layer ID and the Base Layer ID.

The integration of the PDES Tolerance model in the IDEF-1X model of level three is currently under investigation.

5. APPLICATIONS OF THE PROPOSED MODEL

Extensive tests of the proposed model are being conducted at the University of Maryland with the cooperation of the Manufacturing Systems and Technology Center of Westinghouse. Advanced software tools, which use LEP models as input, are being developed to aid the life cycle engineering of MWMs. Two areas of application targeted are i) Automated generation of Group Technology (GT) part codes, i.e. strings of digits that capture key manufacturing and design characteristics [4]; ii) Producibility and cost evaluation of a new part design given both the corresponding GT code and the LEP model.

Figure 8 shows the architecture of the system under consideration. Given the LEP model of a MWM, a coding expert system (CES) will automatically generate a GT code that comprises of two sections. The first one includes information on the mechanical attributes of the MWM, especially those of the ground plane. The second section includes data related to the artwork and its electrical characteristics, as well as critical assembly attributes. The GT codes obtained may be used for conventional GT applications, such as design retrieval, standardization of designs and process plans, variant process planning, etc. Furthermore, the GT code of a new design alongwith its LEP model are the inputs to another expert system that assesses the producibility and approximate cost of the design. The output of this system is fed back to the designer and contains not only feasibility,

manufacturability, and cost ratings, but also specific guidelines for design improvements.

The PDES LEP models used by the system have been implemented in an ORACLE database. The two expert systems are currently under development. The coding expert system is based on well established coding schemes. MULTICLASS [7] is employed to define the mechanical portion of the GT code. It captures information on i) the basic part envelope, ii) the most important mechanical features, iii) material, and tolerances. The information required to determine the part envelope is accessed from Level one of the LEP, while most of the required information on features, material and tolerances is available on Level three. The electrical portion of the GT code is based on the BMCODE system [5,6], which is appropriately adapted to cater for MWMs. Two schemes within that system are used : i) The part assembly attribute scheme that captures components attributes which are critical for the assembly of the MWM. ii) The MWM layout scheme that captures important characteristics of the artwork, and the overall assembly. Most of the information required by these two schemes is accessed from Levels two and three of the LEP model.

The producibility/ cost evaluation module is driven by a list of critical part attributes that have direct impact on the manufacturability of a given design and significant contributions to its cost. Most of these attributes are related to certain digit combinations of the GT code. Depending on the specific values included in each digit combination, the contribution of the corresponding attribute on the manufacturability rating and cost of the design is determined. Information on those attributes that are not directly reflected by the GT code is directly accessed from the PDES database, or provided by the user interactively.

6. CONCLUSIONS

The PDES LEP model for Microwave modules is presented in this paper. It was found that the simplified topological model used in level one of the CalPoly model for Printed Wiring Assemblies (PWAs) is not capable of addressing the complexity of the MWM ground plane. Thus, the standard PDES topological information model (TIM) as well as the features model (FFIM) was employed to describe the geometry and topology of the MWM. Level two of the model was based mostly on the CalPoly work, since the entities used to describe the electrical characteristics of MWMs are similar to the ones proposed for PWAs. A novel model is proposed for level three to capture the design information that is to be used by manufacturing applications. It is constructed on the basis of several standard PDES information models. It integrates the individual layers of the MWM described by the previous levels into a single assembly. The manufacturing features are appended to this assembly, using constructive solid geometry. Material specifications, tolerances and information on passages and test coupons are to be included in this level. The proposed model currently is being tested by manufacturing application systems that assist the life cycle engineering of MWMs.

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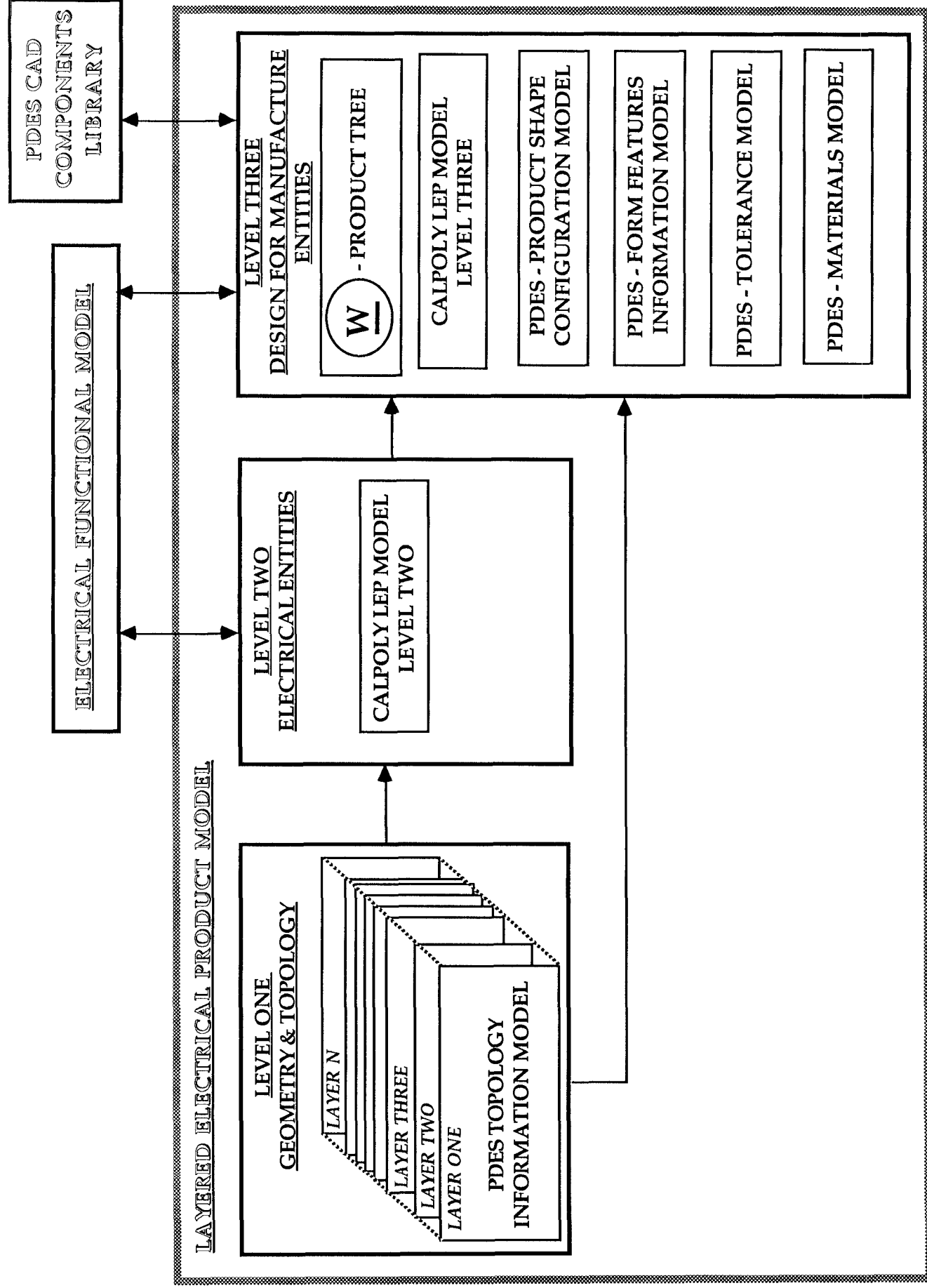


Figure 1 : Proposed integrated LEP model for MWMs

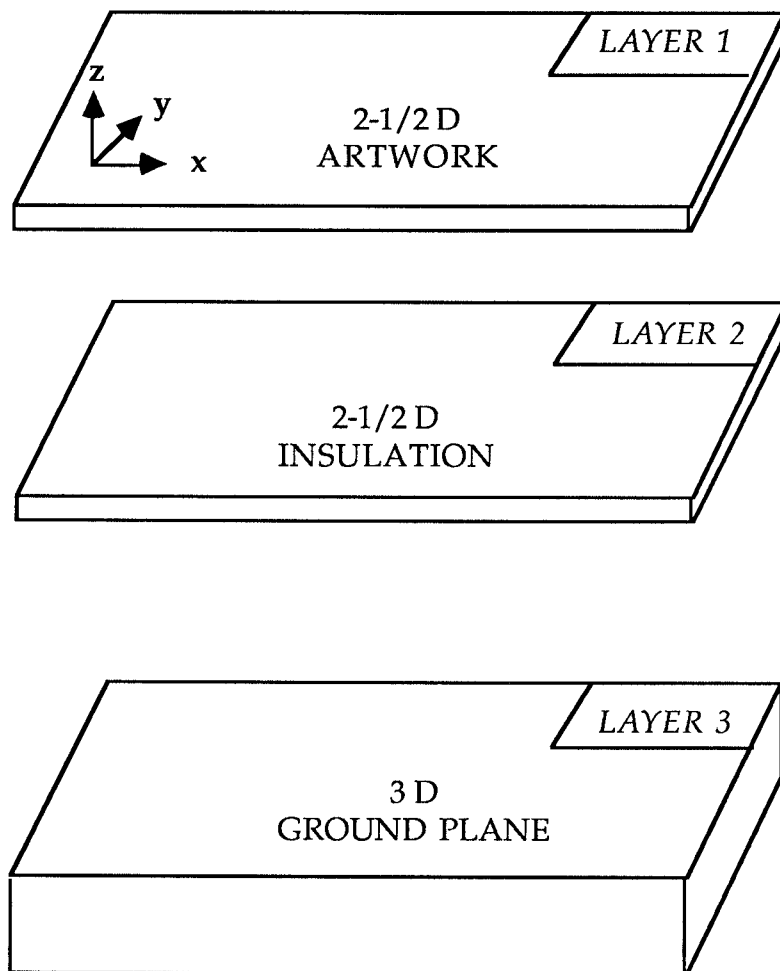


Figure 2 : Schematic representation of a typical 3 - layer MWM

Figure 3 : Artwork for the test part

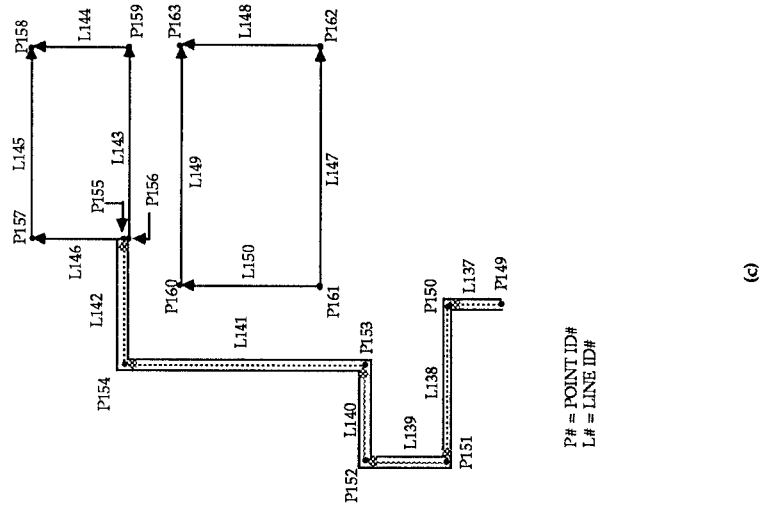
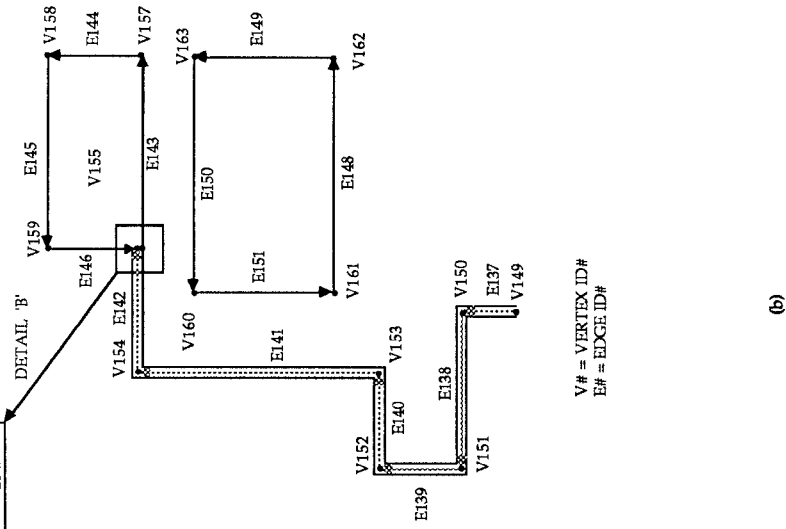
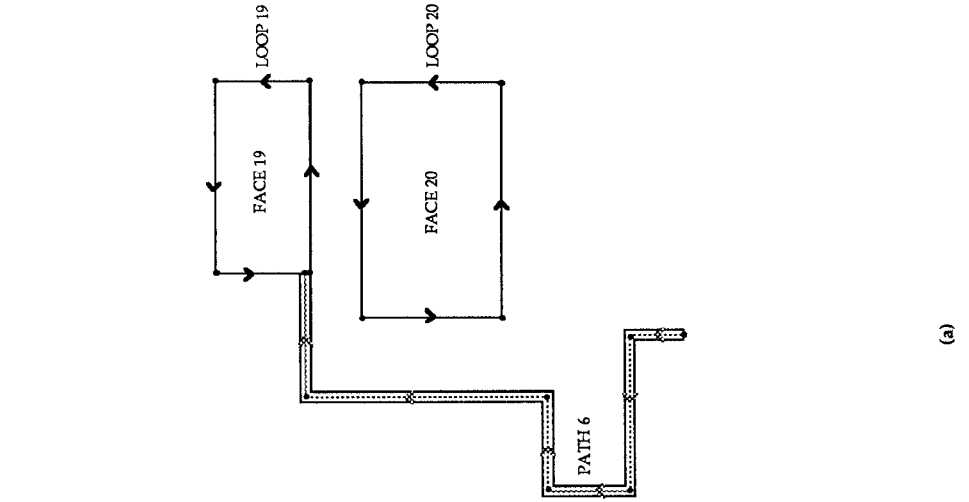


Figure 4 : Example for electrical modelling of artwork detail in level 1

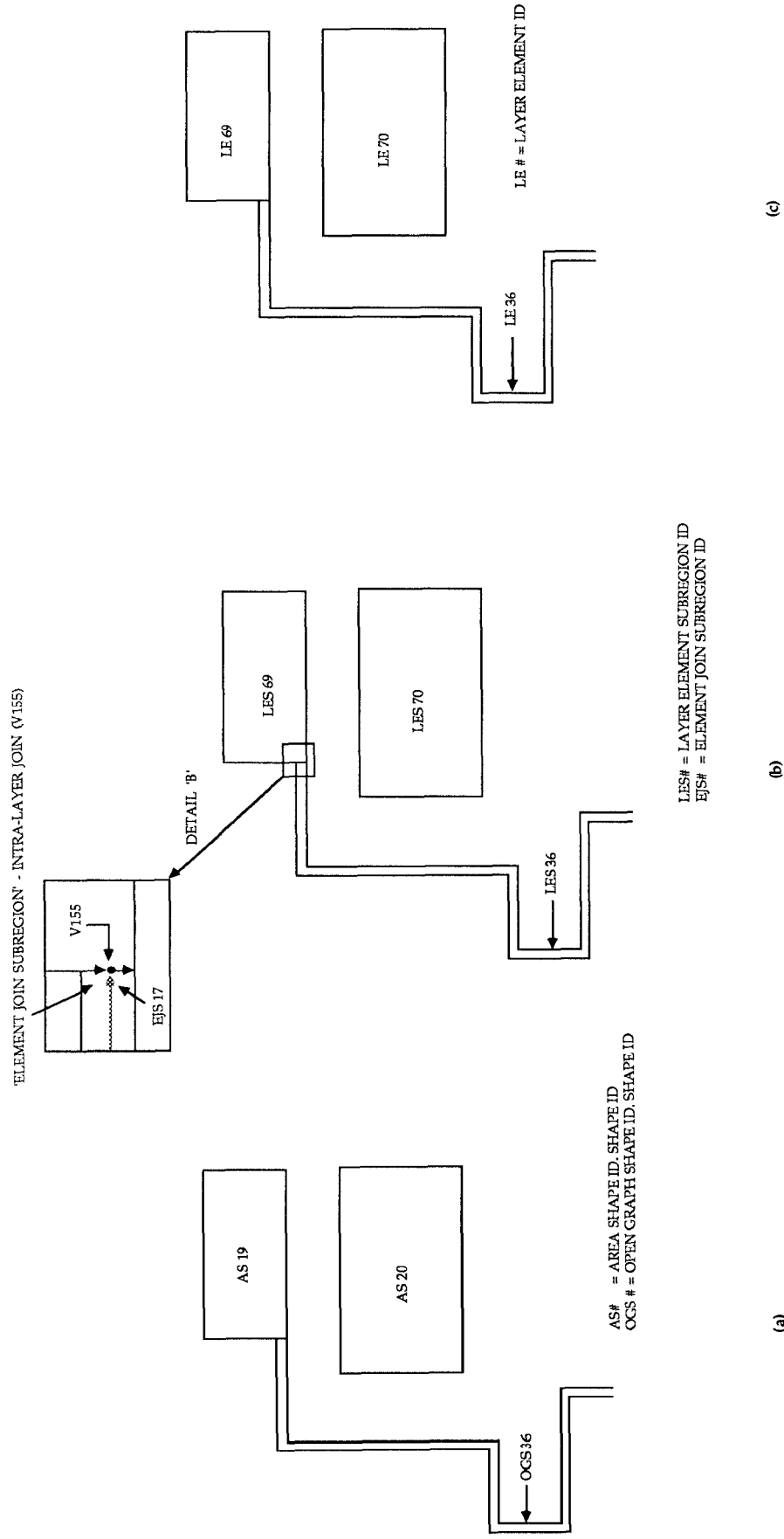


Figure 5 : Example for electrical modelling of artwork detail in level 2

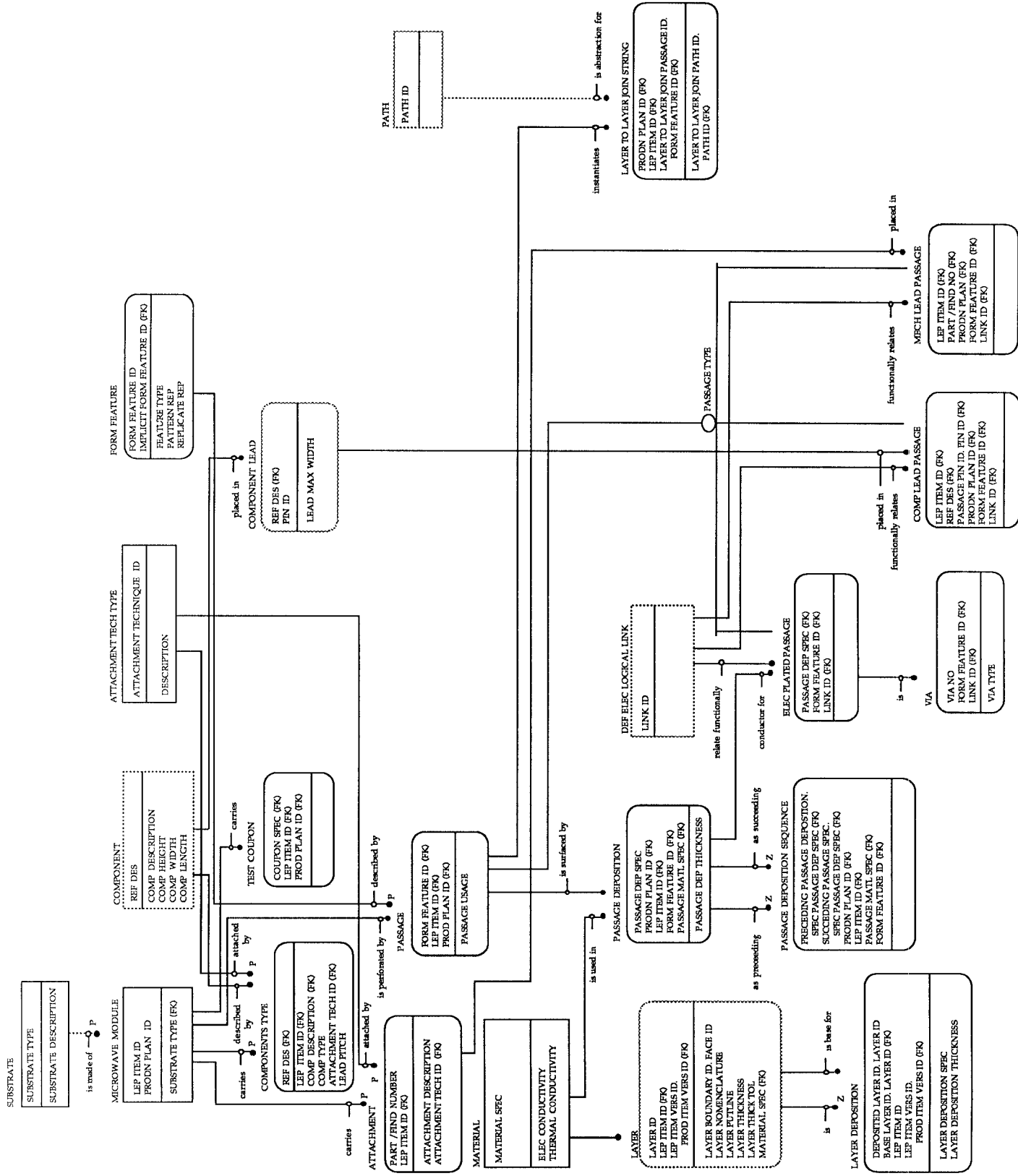


Figure 6 : IDEF - 1X model for proposed LEP level three

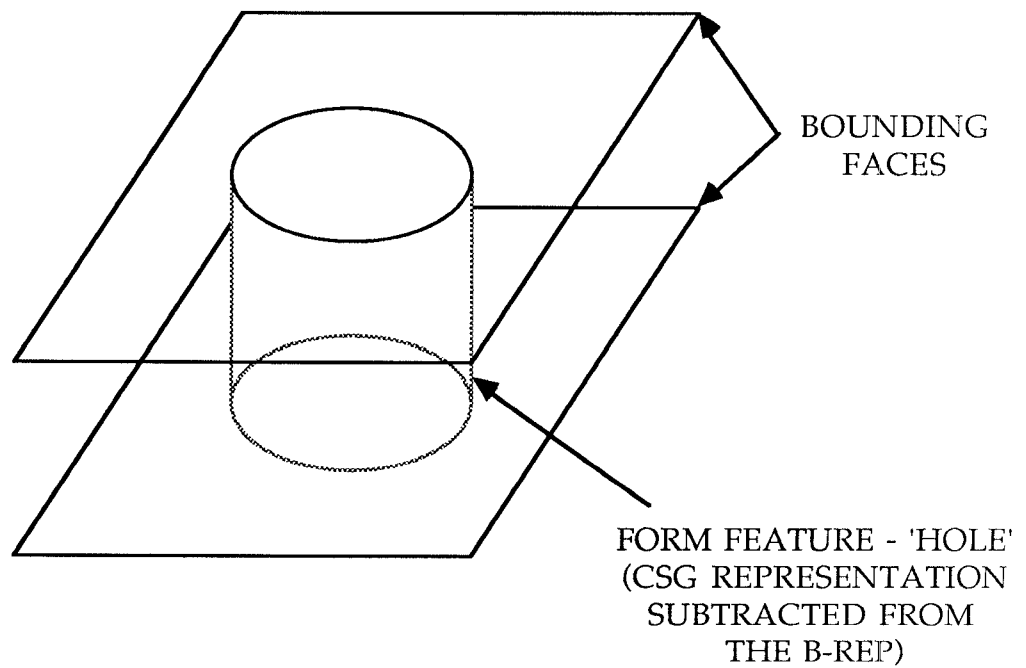
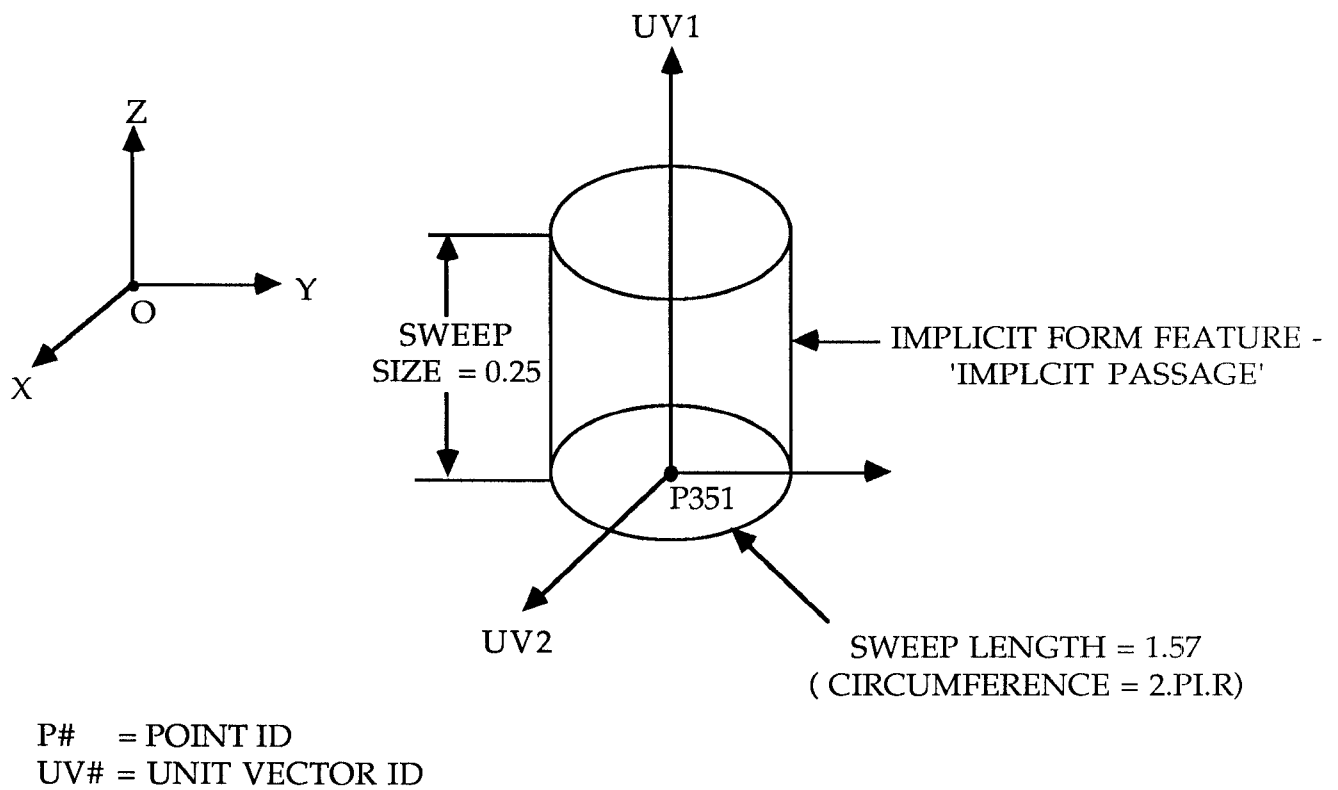


Fig. 7 : Example for solid modelling of features

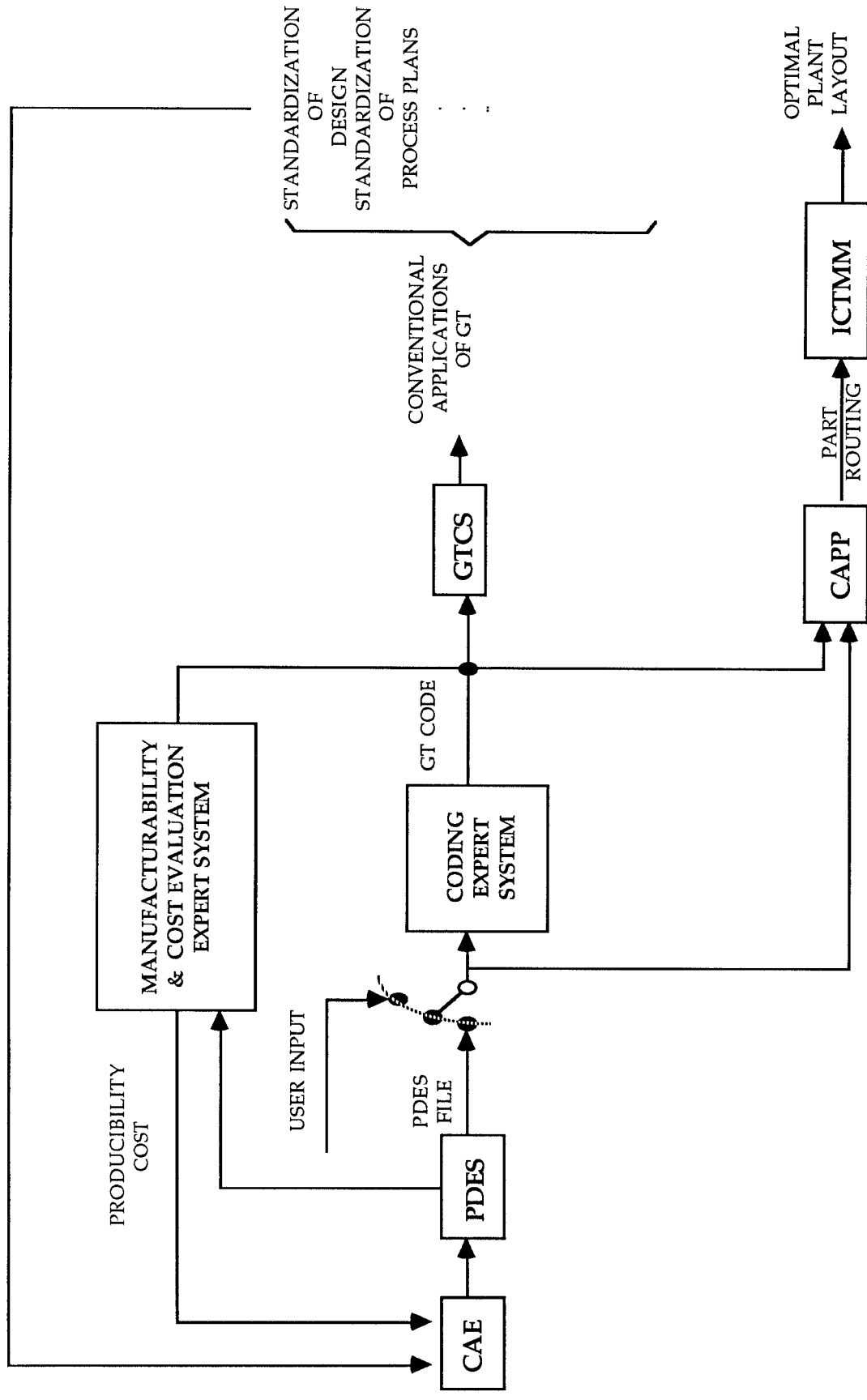


Figure 8 : Proposed System Architecture

Entities-Level 1
Point Direction Curves - Lines - Circles Surfaces Vertex Edge Curve Logical Structure Loop Edge Logical Structure Face Loop Logical Structure Subface Shell Face Logical Structure Component(S) Component Lead(S) Component Lead Vertex(S)

Table 1

Entities-Level 2
Point Shape Explicit Element Point Shape Closed Graph Shape Open Graph Shape Graph Shape Area Shape Shape Icon Text Information Subregion Restricted Subregion Logical Subregion Logical Subregion Shape Intralayer Join Component Lead Join Layer to Layer Join Element Join Subregion Layer Element Shape Layer Element Layer Layer Sequence Layered Electrical Product

Table 2