Geometric Founding and Associativity in ISO 10303-209

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1 Introduction

This document illustrates the many different geometric coordinate frame transformations (foundings) that are possible within ISO 10303-209 (AP209). The examples start with the simplest one part case, and then progress to more complicated transformations.

It should be noted that one or many of these cases may be instantiated in any given AP209 representation. This means that there are a large number of combinations, so in order to minimize the documentation each possible transformation case is documented and implementors should account for any combination of them.

2 Geometry and Product Structure

2.1 Part with Single Shape Representation

Figure 1 represents the simplest case where there is only one shape representation and therefore one representation context.

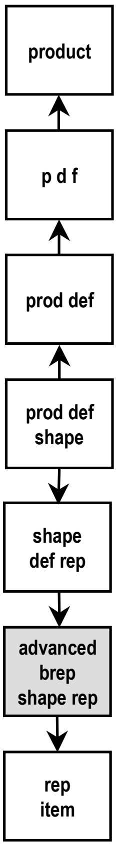


Figure 1 The simplest single part case.

2.2 Part with Single Shape Representation Composed of Sub-Representations

Figure 2 represents a generalization of the simplest case where there is only one shape, however the shape is composed of multiple shape representations each with their own representation context. This is primarily to accommodate the general practice of using many local coordinate frames in the construction of a shape representation. Each portion of the shape representation that lies within a specific local coordinate frame belonging to that representation context.

NOTE that this composition of sub-shape representations may occur in ANY shape representation in an AP209 data structure – part, composite constituent, or FEA shapes.

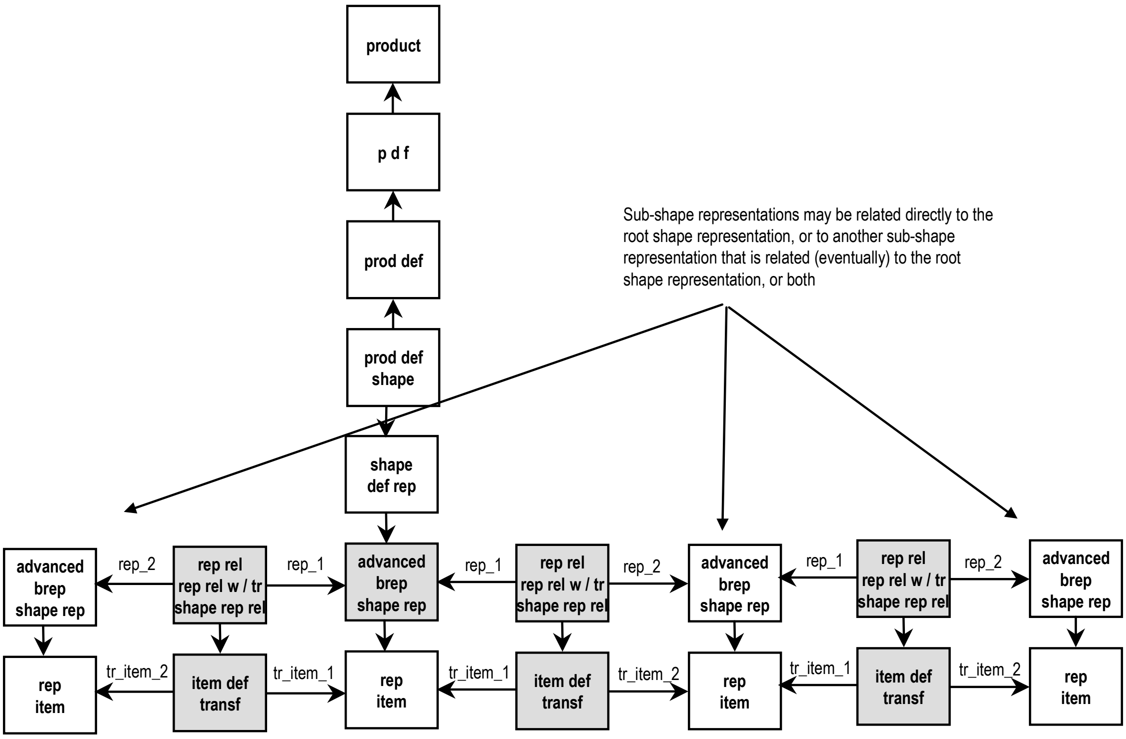


Figure 2 Part with Single Shape Representation Composed of Sub- Shape Representations

2.3 Part with Alternate Shape Representations

Figure 3 represents the case where there is more than one shape representation for the part. Each shape representation is a complete representation of the entire part. The separate representations do not necessarily share the same representation context, though it is most sensible to do this.

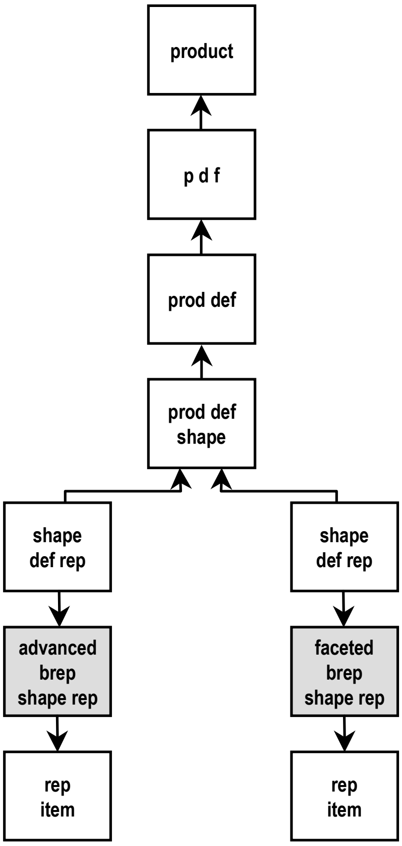


Figure 3 Multiple complete alternate part shape representations

2.4 Part with Multiple Shape Representations

Figure 4 represents the case where there are several different representations that together represent the shape of a part. The separate components of the part shape representation do not necessarily share the same **representation_context**, though it is most sensible to do this. If the separate components of the **shape_representation** have different **representation_contexts**, and therefore coordinate frames, they may be related to each other or to the root **shape_representation** with a transformation as specified in section 2.7.

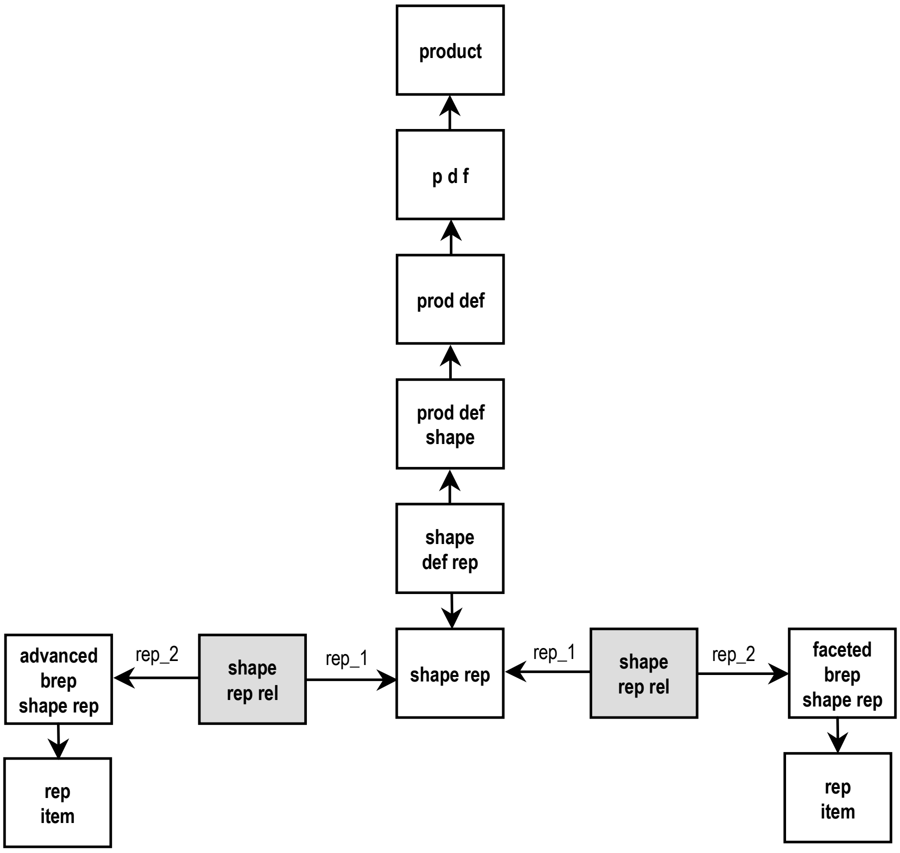


Figure 4 One part shape composed of the sum of two or more shape representations.

NOTE: This is not the structure in the 1998 edition of the AP203 or 1999 AP209 Recommended Practices Guides. This subclause reflects instead the structure documented in ‘PDM Systems/CAD Systems/STEP and Parts’ by Laurence J. McKee dated April 4, 2000.

2.5 Part Shape Based upon Mirroring

Figure 5 represents the case where a part is mirrored. This is the only case where **cartesian_transformation_operator** should be used, as it imposes the restriction that both parts be of the same units. This case is not commonly implemented.

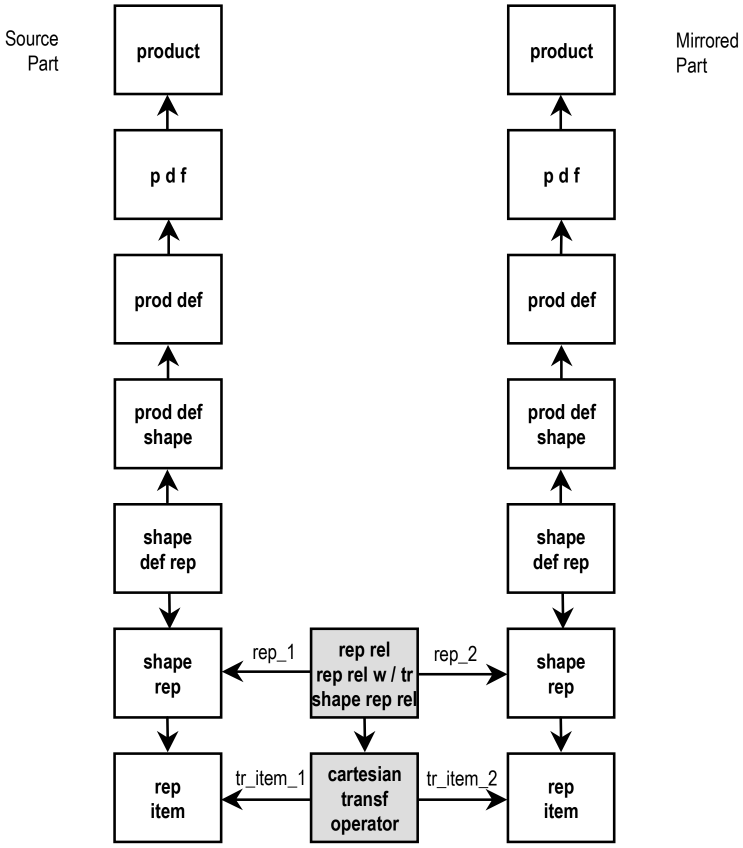


Figure 5 Mirroring of a part.

2.6 Mapping of Shape in an Assembly

Figure 6 represents the case where **mapped_item** is used to perform a coordinate frame transformation between a component and its assembly. Because of the restrictions in STEP geometry AICs that representations mapped together must be of the same type of shape representation this method is now rarely supported by current STEP translators.

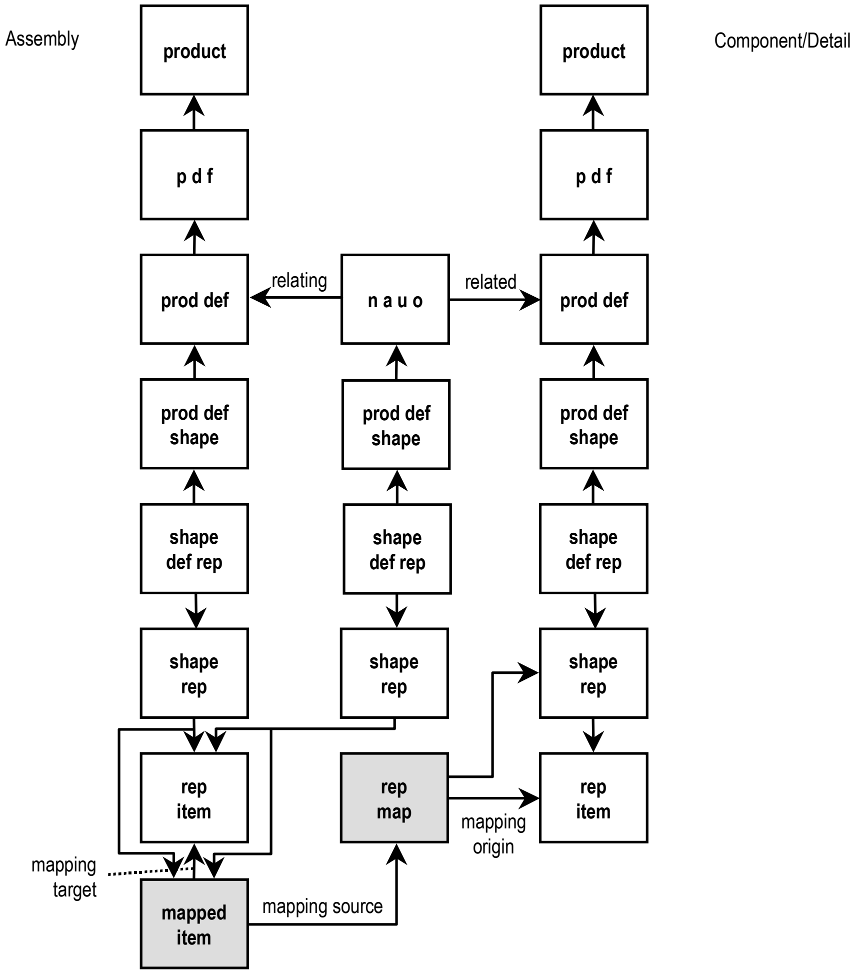


Figure 6 Use of *mapped_item* to relate coordinate frames.

2.7 Referenced Shape in an Assembly

Figure 7 represents the most common case of coordinate frame transformation in AP209. This method is preferred for any coordinate frame transformations, and is used in the remainder of the examples in this document. Note that this methodology lends itself well to managing the coordinate transformations with a coupled PDM/CAD system.

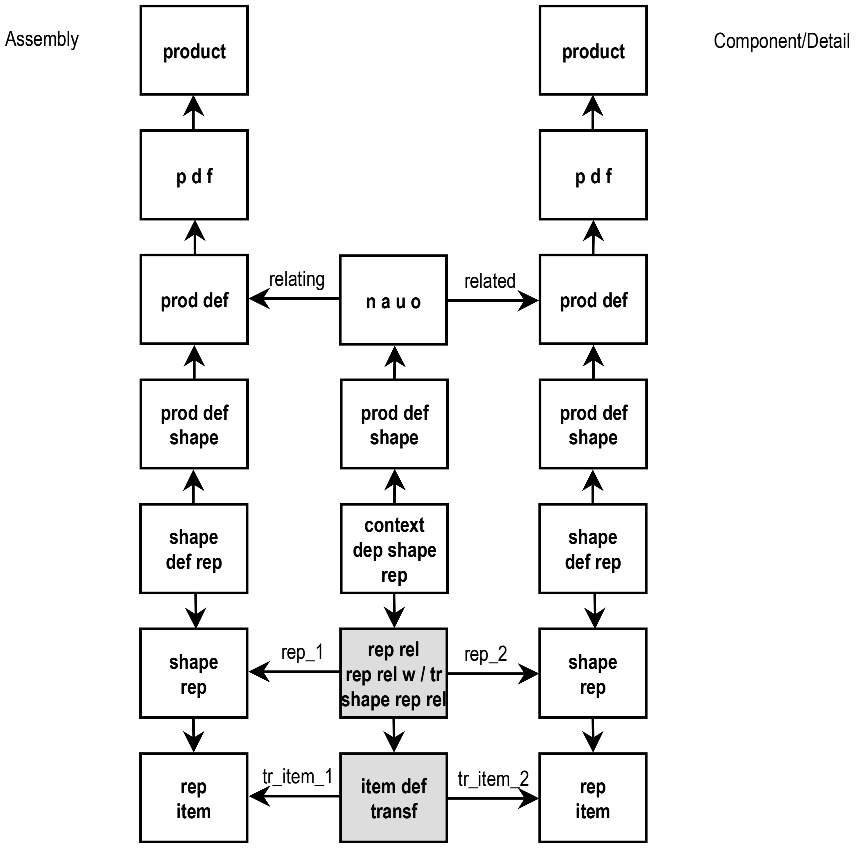


Figure 7 Use of *item_defined_transformation* to relate coordinate frames.

3 Analysis and Design Product Definitions

3.1 All Representations Sharing Same Coordinate Frame

Figure 8 represents the simplest case of shared analysis and design information. All representations – nominal design shape, idealized analysis shape, and fea model – share the same representation context. This case assumes that there are no local coordinate frames in either the shape representations or the fea model. The use of **point_representation** is not necessary in this case. Though the EXPRESS for fea_model does not require a placement (fea_axis2_placement_xd) subtype to define the 'root' coordinate system of the fea_model, the necessities of founding aspects of the fea_model (nodes, elements, state_definitions) require it (see 3.5).

Note that in this diagram that the column of instantiations starting with product through a2p3d on the left is meant to be identical with either the right or left column in the diagram in Figure 7. This is portrayed in Figure 8 by the 'detail' or 'assembly' enumerations of **product_related_product_category** in the upper left of the diagram.

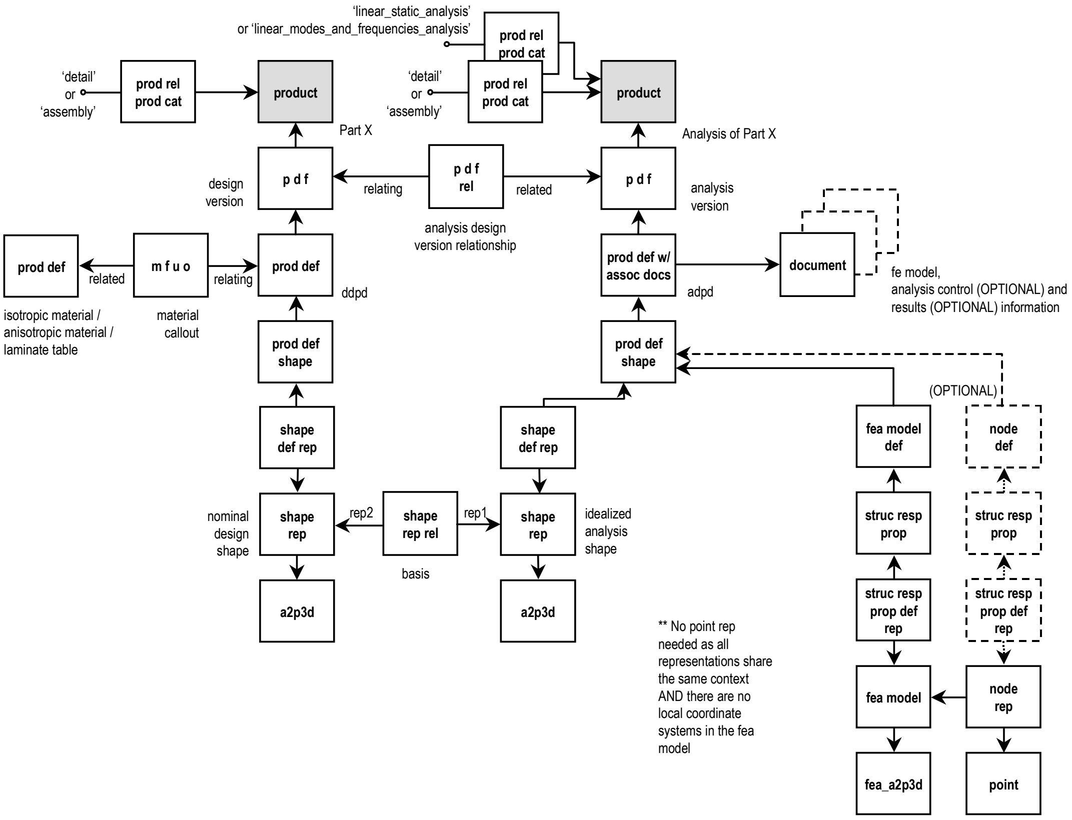


Figure 8 Simplest case of shared design and analysis information.

3.2 Idealized Analysis Shape Founded wrt nominal Design Shape

Figure 9 represents the case where the idealized analysis shape coordinate frame is transformed to the coordinate frame of the nominal design shape.

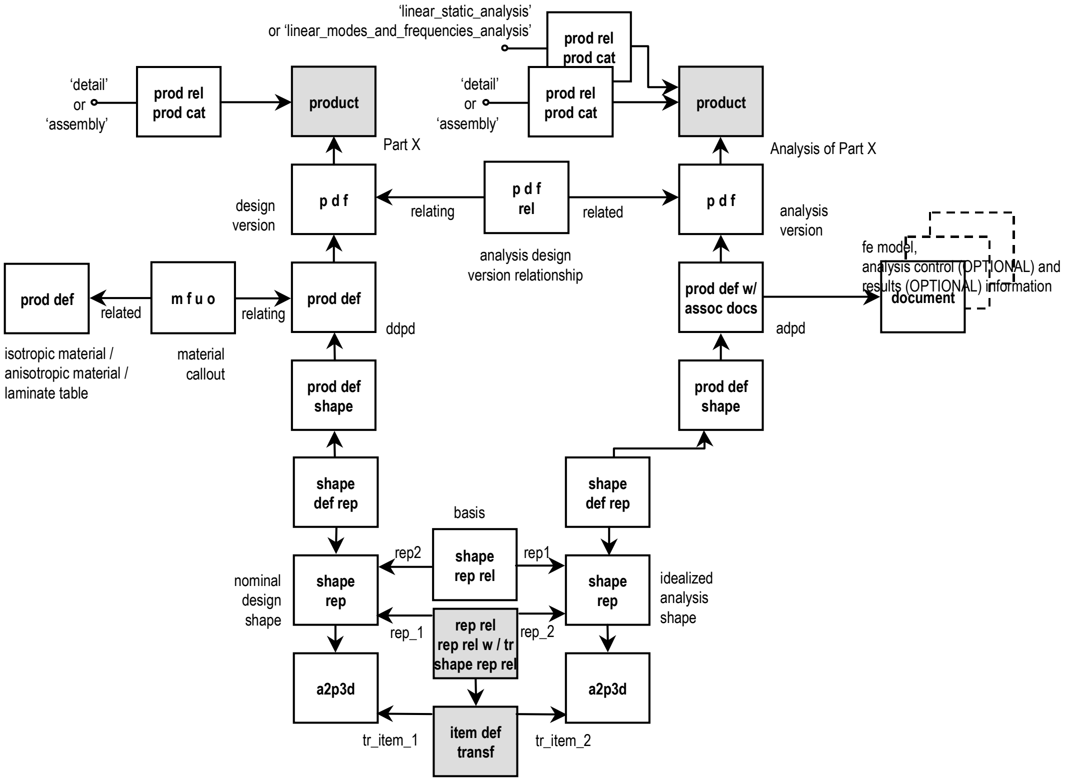


Figure 9 Relating the idealized analysis shape coordinate frame to the nominal design shape.

3.3 FEA Model Founded wrt Either Nominal or Idealized Shapes

Figure 10 represents the case where the coordinate frame of a **fea_model** is transformed to the coordinate frame of either the nominal design shape or the idealized analysis shape.

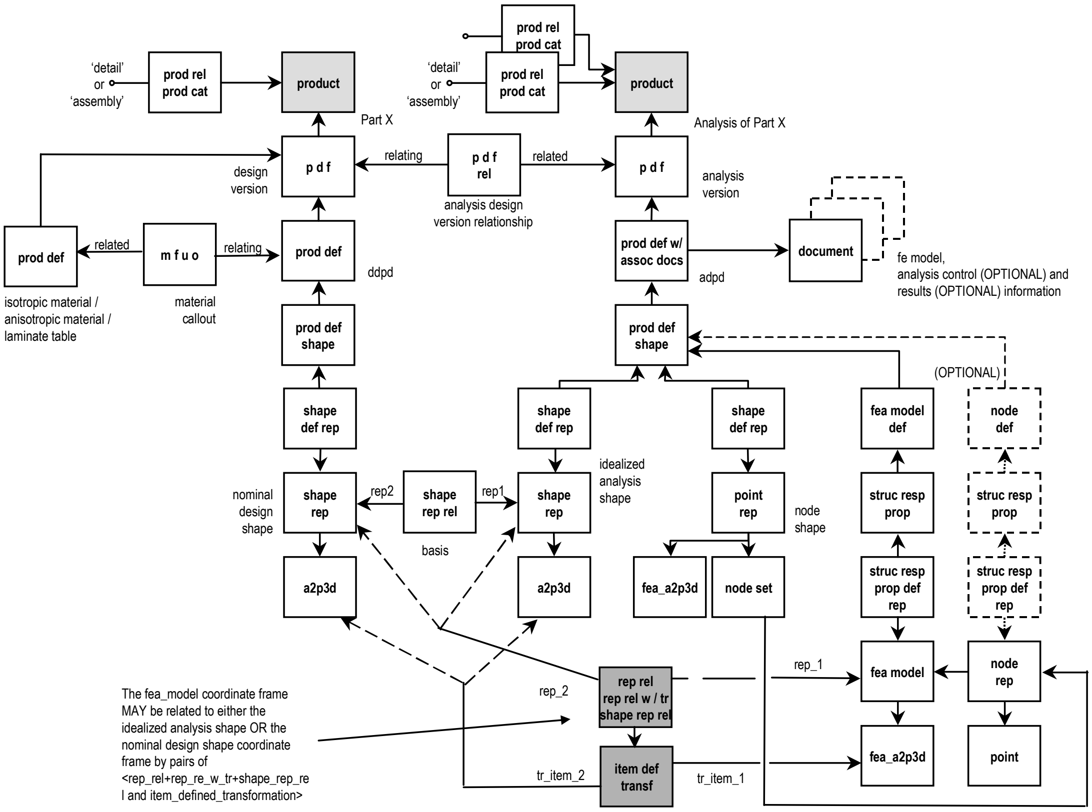
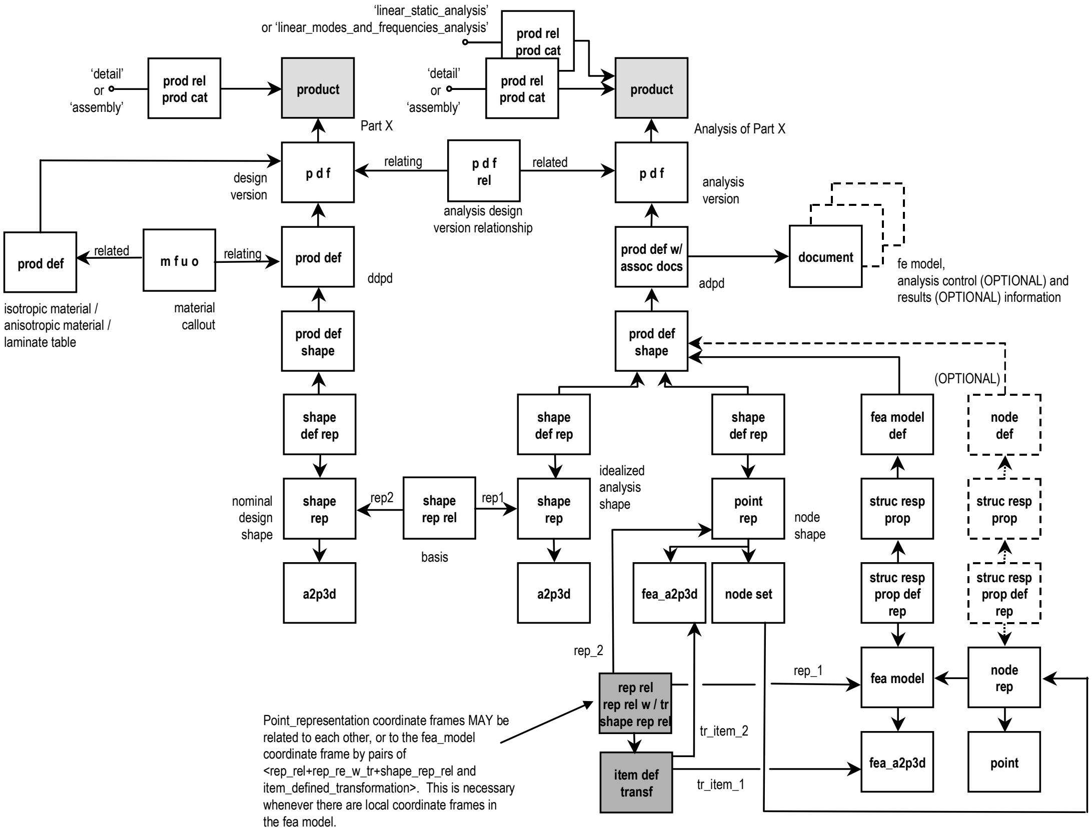


Figure 10 Relating the coordinate frame of a *fea_model* to either nominal or idealized shapes.

3.4 Multiple Coordinate Frames in one FEA Model

Figure 11 represents the case where there are one or more local coordinate frames within a **fea_model**. In this case the use of **point_representation** is necessary to avoid mapping each **node_representation** in a local coordinate frame individually to the **fea_model** basic coordinate frame. The **point_representation** aggregates **node_representations** of a common **represntation_context** to avoid this potentially very large overhead. Note that a local fea coordinate frame may be either related to another fea local coordinate frame or to the **fea_model** basic coordinate frame (specified by the **fea_axis2_placement_3d** referenced by the **fea_model**).



Point_representation coordinate frames MAY be related to each other, or to the fea_model coordinate frame by pairs of <rep_rel+rep_re_w_tr+shape_rep_rel and item_defined_transformation>. This is necessary whenever there are local coordinate frames in the fea model.

Figure 11 Relating multiple local coordinate frames within a *fea_model*.

3.5 Node, Element, and State_Definition Coordinate Frames Within a FEA Model and Associated Analysis

There are many coordinate frames within a finite element model and associated analysis information. In all cases the coordinate frames are founded through the **fea_model** or a subordinate **point_representation**. The **fea_model** may assert to be the ‘root’ coordinate frame, or the **fea_model** may be related to a shape representation that either asserts or is related to (recursively) a **shape_representation** that asserts a ‘root’ coordinate frame.

3.5.1 Node Coordinate Frames

Node coordinate frames for solution information and element normals (see Table 1) are specified by **fea_axi2_placement_xd** entities in the **node_representation .item** list. Node locations and the associated coordinate frames are founded with respect to the **fea_model** or a subordinate **point_representation**.

Table 1 Node Coordinate Frames

node_with_vector
node_with_solution_coordinate_system

3.5.2 Curve Element End Coordinate Frames

Curve element coordinate frames (see Table 2) are specified by **fea_axi2_placement_xd** entities in the **fea_model_xd.items** or subordinate **point_representation.items** lists.

Table 2 Curve Element End Coordinate Frames

curve_element_end_coordinate_system

3.5.3 Element Coordinate Frames

Many element coordinate systems are specified entirely within the **parametric_representation_context** of the element and thus are founded with respect to the parametric coordinate system of the element (see Table 3).

Table 3 Parametric Element Coordinate Frames

constant_surface_3d_element_coordinate_system
parametric_curve_3d_element_coordinate_system
parametric_surface_2d_element_coordinate_system
parametric_surface_3d_element_coordinate_system
parametric_volume_2d_element_coordinate_system
parametric_volume_3d_element_coordinate_system

In the remaining element coordinate systems (see Table 4) the coordinate frame is specified by **fea_axi2_placement_xd** entities in the **fea_model_xd.items** or subordinate **point_representation.items** lists, which are in turn pointed to by the element coordinate system in the **element_representation.items** list.

Table 4 Founded Element Coordinate Frames

aligned_curve_3d_element_coordinate_system
aligned_surface_3d_element_coordinate_system
arbitrary_volume_3d_element_coordinate_system
directionally_explicit_element_coordinate_system_arbitrary
directionally_explicit_element_coordinate_system_aligned
arbitrary_volume_2d_element_coordinate_system
aligned_surface_2d_element_coordinate_system
parametric_curve_3d_element_coordinate_direction
curve_2d_element_coordinate_system

3.5.4 Element State Definition Coordinate Frames

Coordinate frames for element state definitions are specified by either the element coordinate system in **element_representation.items** or in the **fea_model_xd.items** or subordinate **point_representation.items** lists, and pointed to by the **state_definition** entities in Table 5 and Table 6.

Table 5 Element State Definitions

curve_2d_state_coordinate_system
curve_2d_element_value_and_location
curve_2d_element_value_and_volume_location
curve_2d_element_constant_specified_variable_value
curve_2d_element_constant_specified_volume_variable_value
curve_2d_node_field_aggregated_variable_values
curve_2d_node_field_section_variable_values
curve_2d_whole_element_variable_value
curve_3d_state_coordinate_system
curve_3d_element_value_and_location
curve_3d_element_value_and_volume_location
curve_3d_node_field_aggregated_variable_values
curve_3d_node_field_section_variable_values
curve_3d_element_constant_specified_variable_value
curve_3d_element_constant_specified_volume_variable_value
curve_3d_whole_element_variable_value
surface_2d_state_coordinate_system
surface_2d_element_boundary_constant_specified_surface_variable_value
surface_2d_element_boundary_constant_specified_variable_value
surface_2d_element_boundary_edge_constant_specified_surface_variable_value
surface_2d_element_boundary_edge_constant_specified_variable_value
surface_2d_element_boundary_edge_whole_edge_variable_value
surface_2d_element_boundary_whole_face_variable_value
surface_2d_element_constant_specified_variable_value
surface_2d_element_constant_specified_volume_variable_value
surface_2d_element_value_and_location
surface_2d_element_value_and_volume_location
surface_2d_node_field_aggregated_variable_values
surface_2d_node_field_section_variable_values
surface_2d_whole_element_variable_value
surface_3d_state_coordinate_system
surface_3d_element_boundary_constant_specified_surface_variable_value
surface_3d_element_boundary_constant_specified_variable_value
surface_3d_element_boundary_edge_constant_specified_surface_variable_value
surface_3d_element_boundary_edge_whole_edge_variable_value
surface_3d_element_boundary_whole_face_variable_value
surface_3d_element_constant_specified_variable_value
surface_3d_element_constant_specified_volume_variable_value
surface_3d_element_value_and_location
surface_3d_element_value_and_volume_location
surface_3d_node_field_aggregated_variable_values
surface_3d_node_field_section_variable_values
surface_3d_whole_element_variable_value

Table 6 Element State Definitions - Continued

volume_2d_element_coordinate_system
volume_2d_element_boundary_constant_specified_variable_value
volume_2d_element_boundary_edge_constant_specified_volume_variable_value
volume_2d_element_boundary_edge_whole_edge_variable_value
volume_2d_element_boundary_whole_face_variable_value
volume_2d_element_constant_specified_variable_value
volume_2d_element_value_and_location
volume_2d_node_field_variable_definition
volume_2d_whole_element_variable_value
volume_3d_element_coordinate_system
volume_3d_element_boundary_constant_specified_variable_value
volume_3d_element_boundary_edge_constant_specified_volume_variable_value
volume_3d_element_boundary_edge_whole_edge_variable_value
volume_3d_element_boundary_whole_face_variable_value
volume_3d_element_constant_specified_variable_value
volume_3d_element_value_and_location
volume_3d_node_field_variable_definition
volume_3d_whole_element_variable_value

3.5.5 Nodal State Definition Coordinate Frames

Nodal state coordinate frames are specified by **fea_axi2_placement_xd** entities in the **fea_model_xd.items** or subordinate **point_representation.items** lists and are pointed to by the **state_definition** entities in Table 7.

Table 7 Nodal State Definition Coordinate Frames

point_constraint
point_freedom_and_value_definition
curve_constraint
curve_freedom_and_value_definition
surface_constraint
surface_freedom_and_value_definition
solid_constraint
solid_freedom_and_value_definition
single_point_constraint_element
nodal_freedom_and_value_definition
linear_constraint_equation_nodal_term
element_nodal_freedom_terms
field_variable_element_group_value
field_variable_whole_model_value
stationary_mass
nodal_dof_reduction

3.6 Finite Element Model and Analysis Geometric Associativity

There are many types of geometric associativity possible between Finite Element entities and shape representations. These vary from implicit associations such as in the coordinate of a node to explicit links forged with association operators between properties and representation items. In the latter cases a special entity called **analysis_item_within_representation** is used to provide the ability to associate Finite Element entities to specific **representation_item**s within a **representation_con**text – avoiding the very complicated necessity of creating a special **representation** that has just the required **representation_item** and a **representation_relationship** to the founding **representation**.

In all cases the associativity does not provide geometric founding – only the associations to a representation context provide the founding.

3.6.1 Node to Geometric Location

This is an implicit associativity brought about by the reference of a **point** subtype in the **representation_item** list of a **node_representation**. This associativity brings the capability of defining a nodal location from a **cartesian_point**, a **point_on_curve** , a **point_on_surface**, a **point_replica**, or a **degenerate_pcurve.**

3.6.2 Node to Geometric Representation Item

The Node to Geometric Representation Item is an explicit associativity brought about by the reference of a **representation_item** through the reference of an **analysis_item_within_representation** by a **node_geometric_relationship**. The **representation_item** is constrained to be a **geometric_representation_item** by a rule in **node_geometric_relationship**. Either a single Node or a group of Nodes may be associated to the **geometric_representation_item**.

Note that this is of interest for associating Nodes with mesh generation geometry.

3.6.3 Element Aspect to Geometric Representation Item

The Element to Geometric Representation Item is an explicit associativity brought about by the reference of a **representation_item** through the reference of an **analysis_item_within_representation** by a **element_geometric_relationship**. The **representation_item** is constrained to be a **geometric_representation_item** by a rule in **element_geometric_relationship**. Either a single Element or a group of Elements may be associated to the **geometric_representation_item**.

A further constraint is enforced within **element_geometric_relationship** by the function **consistent_geometric_relationship** that enforces a reasonable set of relationships between geometric aspects of an Element and a **geometric_representation_item**. These relationships are summarized in Table 8.

Note that these relationships are of interest for representing information for P-Elements and associating Element aspects with mesh generation geometry.

3.6.4 Element Property to Geometric Representation Item

The Element Property to Geometric Representation Item is an explicit associativity brought about by the reference of a **representation_item** through the reference of an **analysis_item_within_representation** by either a **fea_curve_section_geometric_relationship** or a **fea_surface_section_geometric_relationship**. The **representation_item** is constrained to be a **geometric_representation_item** by a rule in both relationships.

Note that these relationships are of interest when applying Surface and Curve Element Properties directly to geometry with no associated finite element model.

Table 8 Valid combinations of Element Aspect and Geometric Representation Item

Element Aspect	**Allowed Geometric Representation Item**
element_volume	solid_model
volume_3d_face	surface, face_surface
volume_2d_face	surface, face_surface
volume_3d_edge	curve, edge_curve
volume_2d_edge	curve, edge_curve
surface_3d_face	surface, face_surface
surface_2d_face	surface, face_surface
surface_3d_edge	curve, edge_curve
surface_2d_edge	curve, edge_curve
curve_edge	curve, edge_curve

3.6.5 Material Property to Geometric Representation Item

The Material Property to Geometric Representation Item is an explicit associativity brought about by the reference of a **representation_item** through the reference of an **analysis_item_within_representation** by a **fea_material_property_geometric_relationship**. The **representation_item** is constrained to be a **geometric_representation_item** by a rule in **fea_material_property_geometric_relationship**.

Note that these relationships are of interest when applying Material Properties directly to geometry with no associated finite element model.

3.6.6 Constraint(s) to Geometric Representation Item

The Constraint to Geometric Representation Item is an explicit associativity brought about by the reference of a **representation_item** through the reference of an **analysis_item_within_representation** by the constraint relationships in the Constraint column of Table 9. A constraint is enforced within the Constraint entities in column 1 of Table 9 that enforces a reasonable set of relationships between a constraint and a **geometric_representation_item**.

The Constraint is applied to all nodes that are associated to the Geometric Representation Item. This would typically be the case when the nodes are part of a mesh generated from geometry.

Note that these relationships are also of interest when applying Constraints directly to geometry with no associated finite element model.

Table 9 Valid Geometric Representation Items for Types of Constraints

Constraint	Allowed Geometric Representation Item
point_constraint	point, vetex_point
curve_constraint	curve, edge_curve
surface_constraint	surface, face_surface
solid_constraint	solid_model

3.6.7 Element and Node Output to Geometric Representation Item

The Element and Node Output to Geometric Representation Item is an explicit associativity brought about by the reference of a **representation_item** through the reference of an **analysis_item_within_representation** by the output references in Table 10.

Note that this is of interest for associating Node and Element state definition information with mesh generation geometry.

Note that these relationships are also of interest when applying Node and Element state definition information directly to geometry with no associated finite element model.

Table 10 Node and Element Output References

node_output_reference
curve_2d_element_output_reference
curve_3d_element_output_reference
surface_2d_element_output_reference
surface_3d_element_output_reference
volume_2d_element_output_reference
volume_3d_element_output_reference

4 Composite Constituent Product Definitions

The simplest case for composite constituent product definitions is when all product definitions use the same **representation_context**, similar to the case for a finite element analysis presented in 3.1. No transformations are required for the simplest case. This applies to a Laminate Table subtype and to any Ply or Composite Constituent shape representations.

This is by far the most frequently instantiated case.

4.1 Referenced Shape in an Assembly with Additional Laminate Table Representation

Figure 12 represents the case where the laminate table subtype is founded with respect to the component/detail within an assembly. Note that it is not required for the component/detail be in an assembly, and that the laminate table subtype could also be related to the assembly.

This is the second most frequently instantiated case.

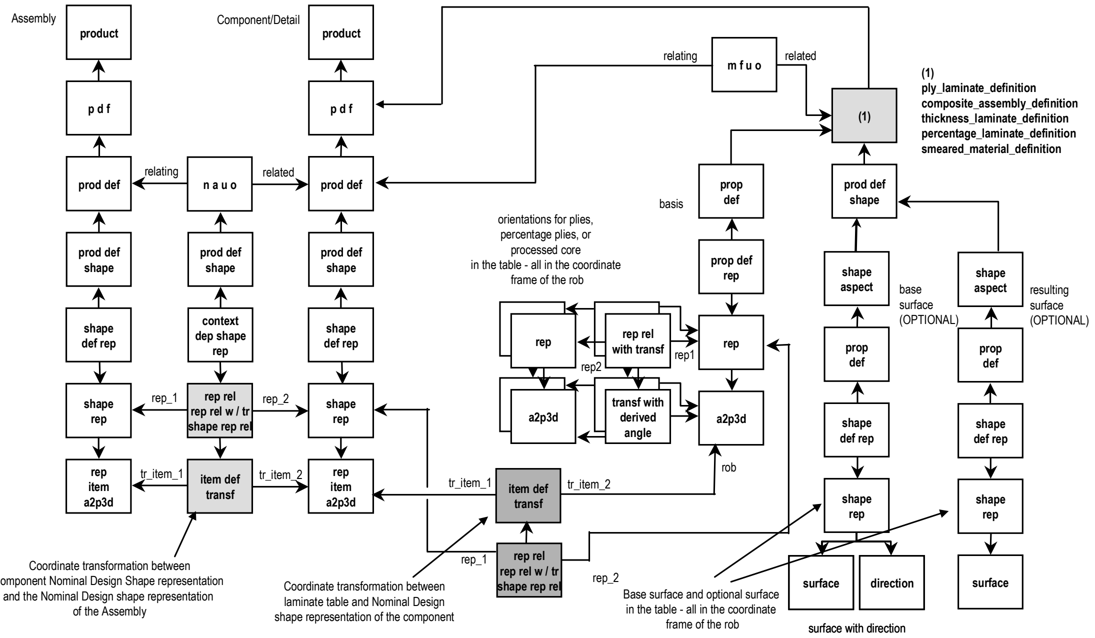


Figure 12 Referenced Shape in an Assembly with Additional Laminate Table Representation - Most General Geometric Founding Case

4.2 Founding of Ply Subtypes and Composite Constituents with Respect to a Laminate Table subtype – the Most General Case

The Ply shape subtypes and Composite Constituent shapes listed in Table 11 represent the different types of shape indicated on the right – hand side of Figure 13. Any of these shapes may be founded with respect to each other, or with respect to the Laminate Table subtype that they are a member of.

This is a rarely instantiated case included for completeness.

Table 11 Ply Subtypes and Composite Constituents

Laid Ply Shape
Flat Pattern Ply Shape
Projected Ply Shape – Surface Ply Shape
Projected Ply Shape – View Ply Shape
Processed Core Shape
Filament Laminate Shape
Ply Laminate Shape
Composite Assembly Shape

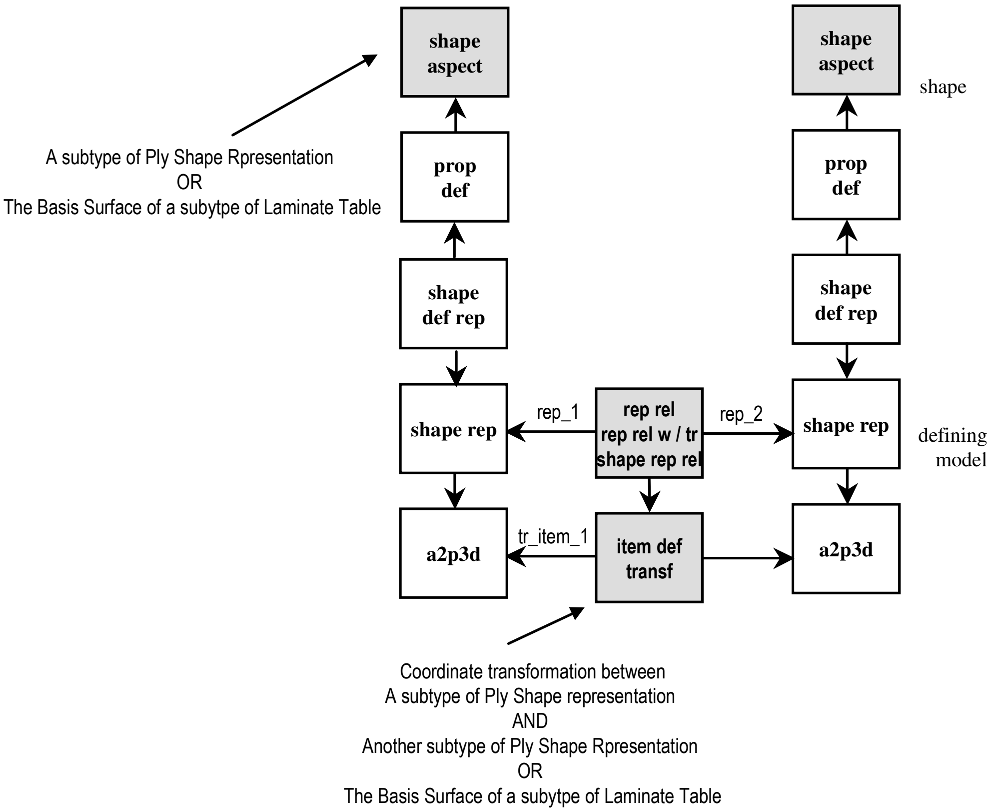


Figure 13 Founding of Ply and Composite Constituent Shapes – Most General Case

5 Acknowledgments

Portions of this paper are based upon ‘PDM Systems/ CAD Systems/ STEP and Parts’ by Laurence J. McKee, April 4, 2000.