A tale of
Variability and Electrical Transformers

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Universidad de los Andes

Wait !!... Transformers ?

- What is the relationship among **Software Product Lines** and **Electrical Transformers**?

- Is this the right conference?

Variability Management

Electrical Transformers

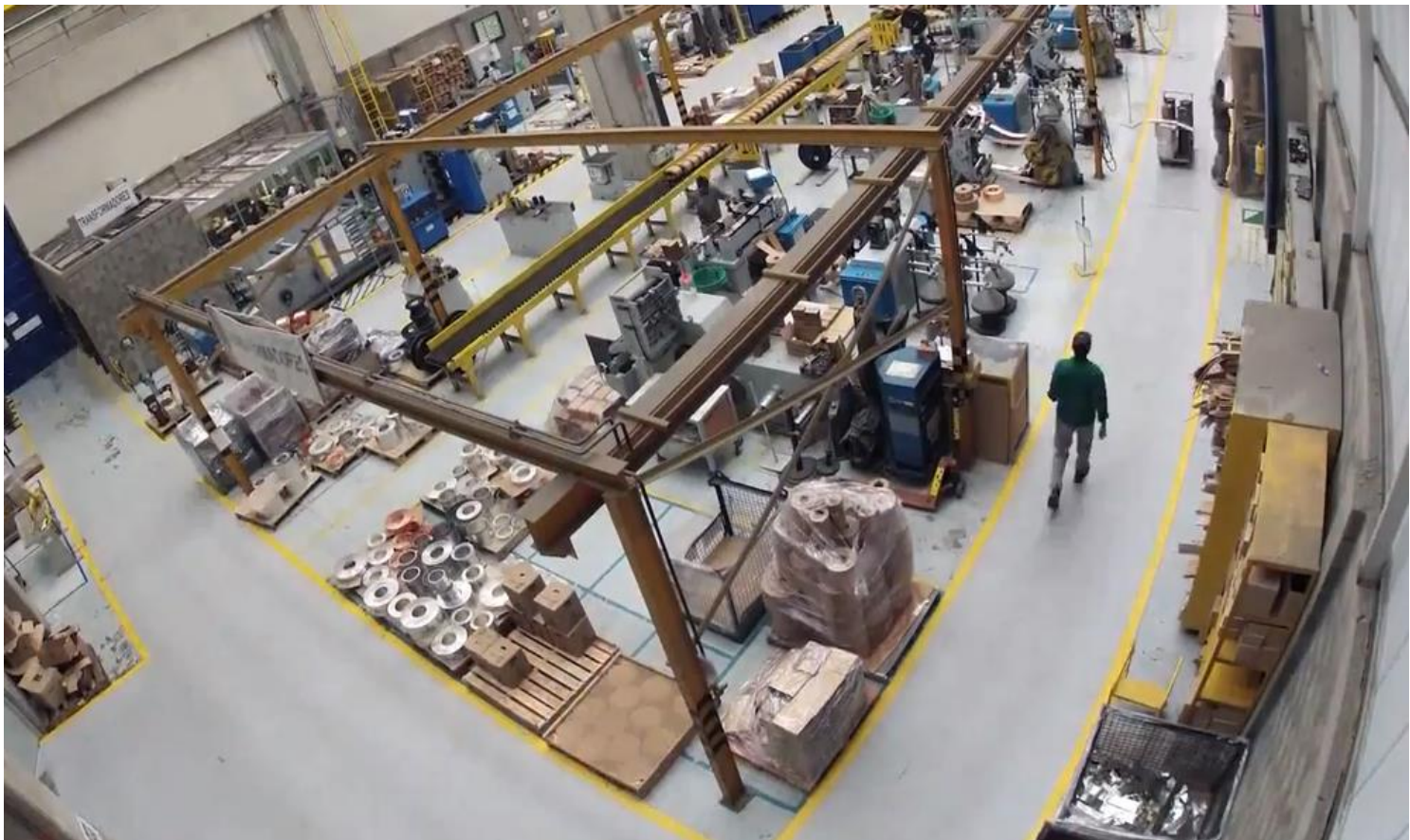SIEMENS produces electrical transformers in Colombia

There is a facility located at 8,5 kms of the center of Bogotá

Siemens Transformers

+350 persons
+15000 units/yr.
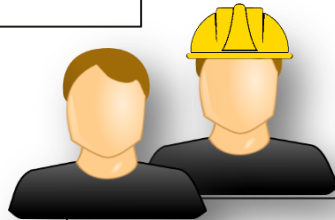
Clients across all America

Multiple standards and norms must be supported

... just for Colombia, there many national and proprietary standards for each single family.
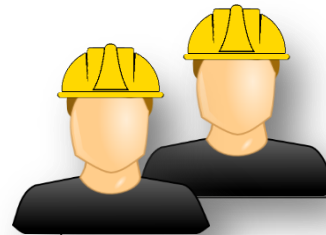
Bid
Process

Design Process

Manufacturing

Bid Process

I want an electrical transformer with
Power of 15KVA
a Low Voltage of 214V
and a High Voltage of 4160V
To be installed in Buenos Aires

Customer
Customer
Requests

Sales Engr
Bid Engr
Bids
Proposals

Design Process

Electrical Design

Mechanical Design

Accessories
Packing
Shipping
…

Design Process

Electrical Design

Mechanical Design

Accessories Packing Shipping ...

Some Issues to tackle

Electrical Design

Mechanical Design

Accessories Packing Shipping ...
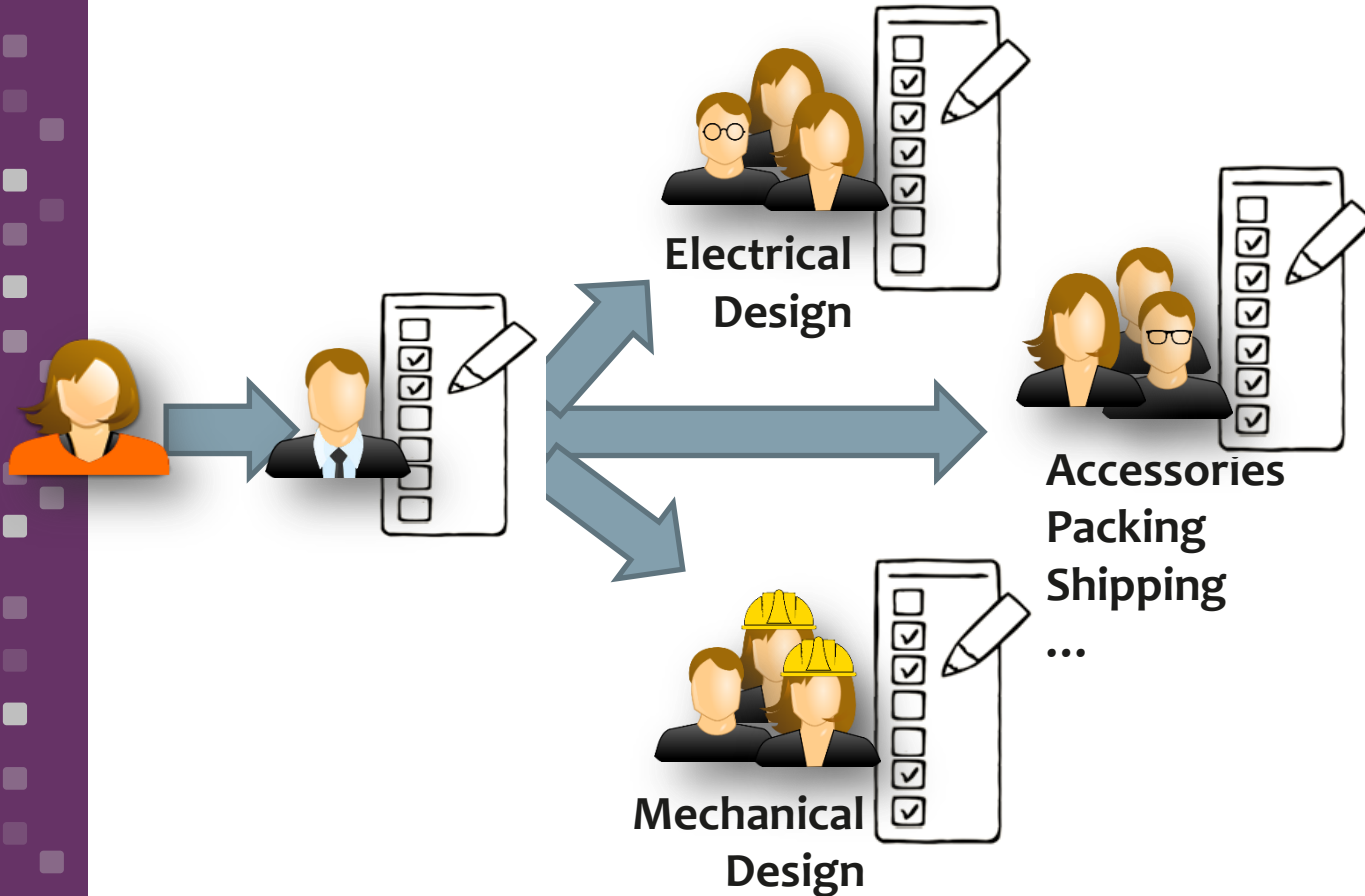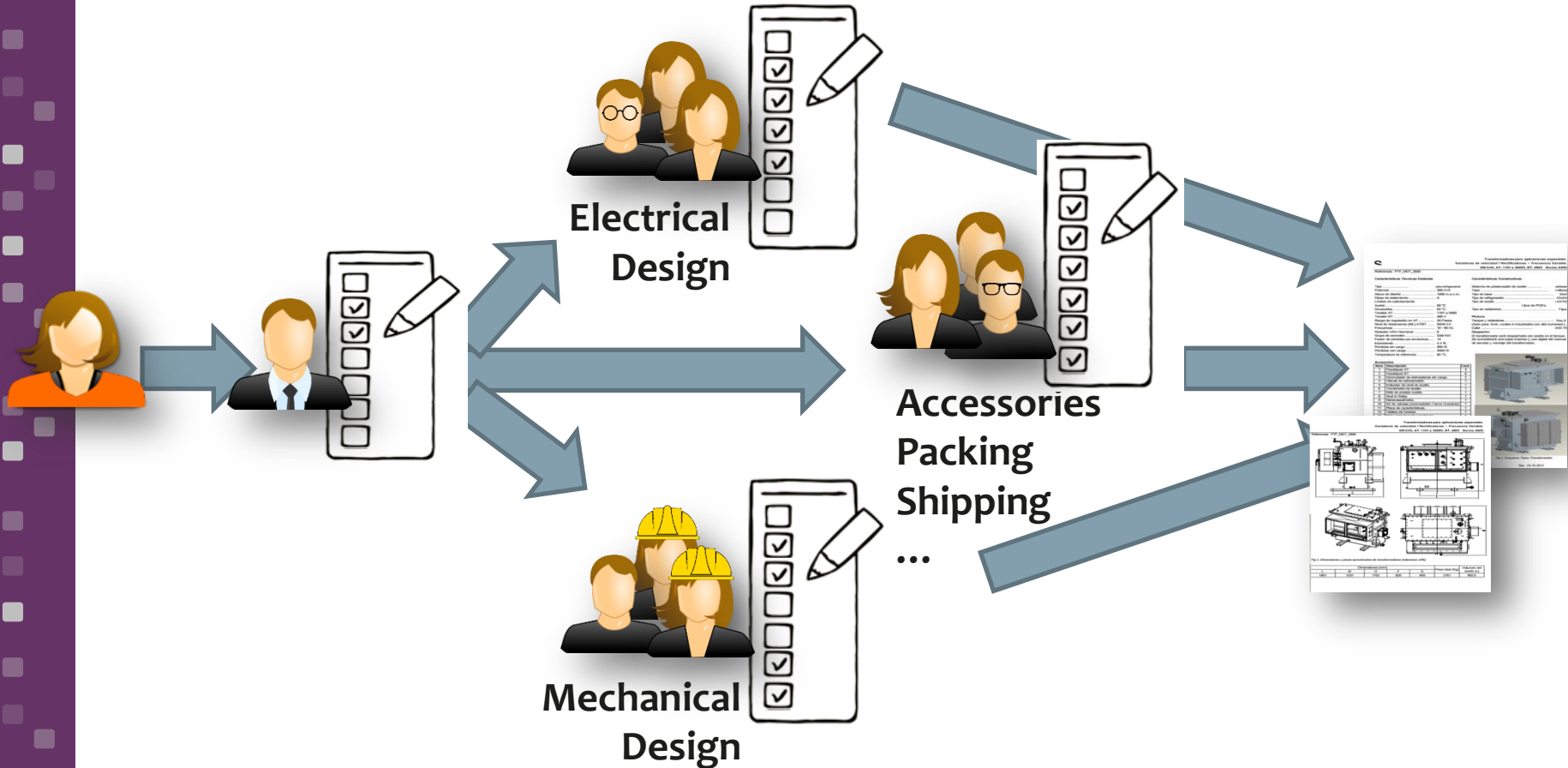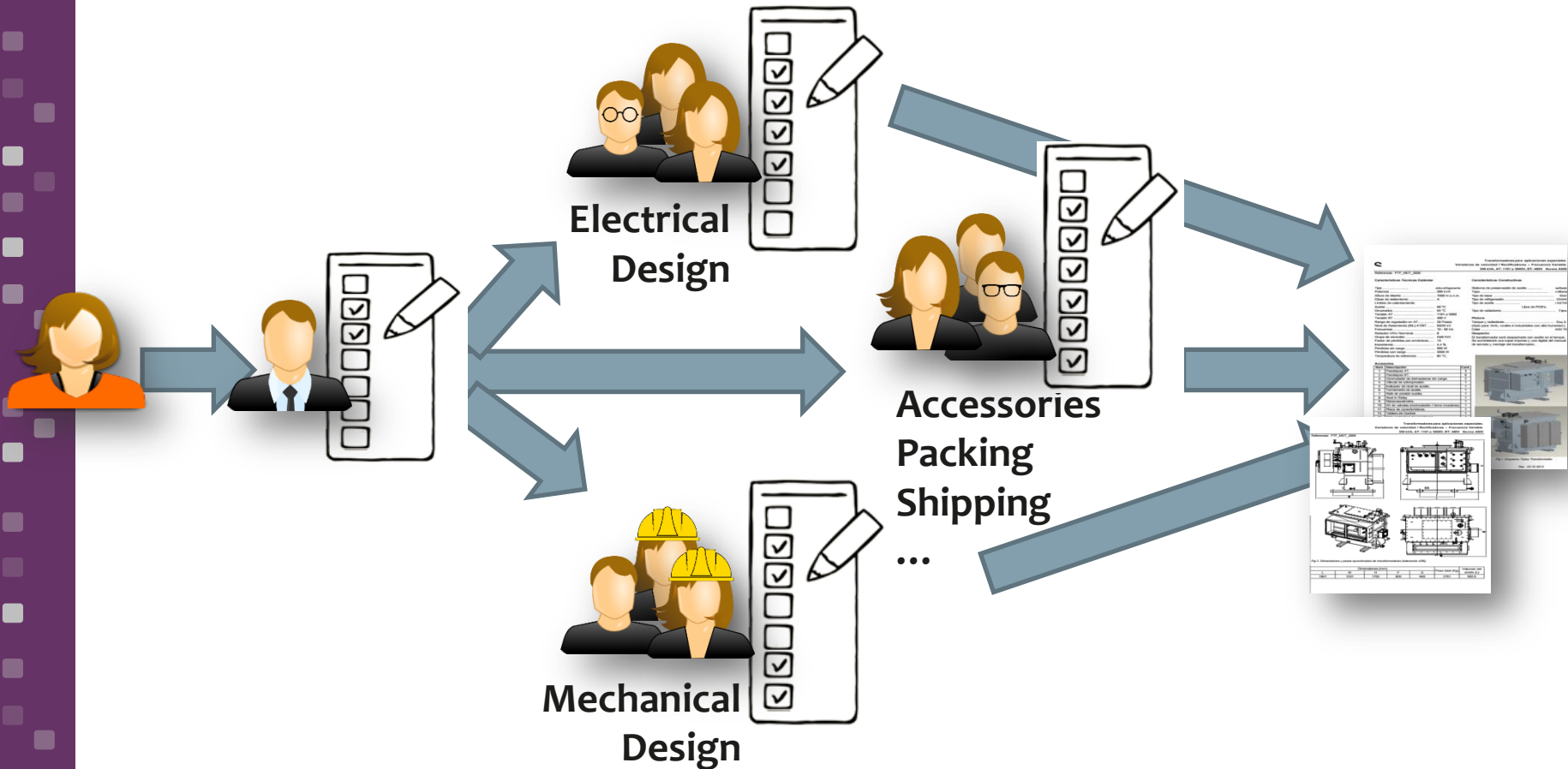
... for the Sales Engineers

- Detect inconsistencies in the client's requests
- Identify inconsistencies with standards
- Identify already designed similar transformers
- Complete the specification
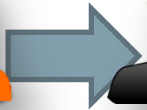
… for the Engineering Design Groups

Electrical Design

Accessories Packing Shipping …

Mechanical Design

- Detect inconsistencies with decisions in other domains
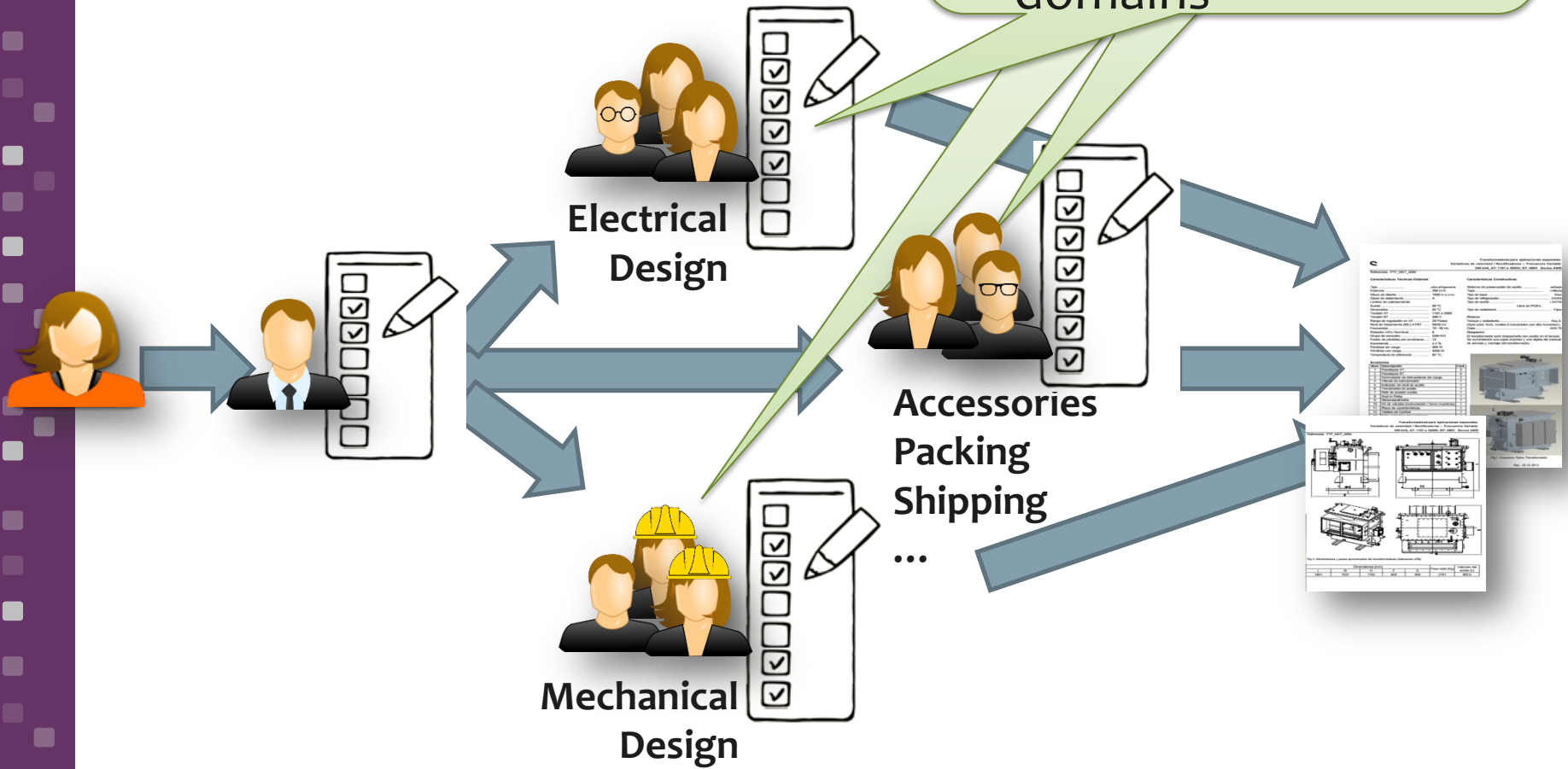
For Early detection of conflicts

Approach: Feature-Based Configuration Process (using a single feature model)

Our First Attempt:
A Single Feature Model
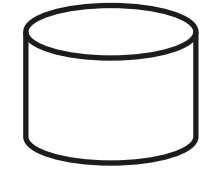
Variability
Reverse
Engineering

Catalog of
Products

Our First Attempt: A Single Feature Model

Variability
Reverse
Engineering

Catalog of
Products

Electrical Transformer
- Standard
  - [1..*]
    - NTC 3997
- Type
  - Transformer Type
    - [1..1]
      - Pole Mounted
      - Pad Mounted
- Electrical Thermal and Acoustic
  - Electrical
    - Power
      - [1..1]
        - 15KVA
        - 30KVA
    - High Voltage
      - [1..1]
        - 4160V
        - 11400V
    - Low Voltage
      - [1..1]
        - 214V
        - 228V
  - Thermal
    - Cooling Method
      - [1..*]
        - ONAN
   - ONAF
  - Acoustic
    - Noise Level
      - NEMA TR1
- Mechanical
  - Tank type
    - [1..1]
      - Sealed Tank
      - Conservator Tank
- ETA Accessories
  - Oil Level Indicator
    - [1..1]
      - OLI Alarm
      - OLI Trip
  - Buchholz Relay
    - [1..1]
      - BR Alarm
      - BR Trip
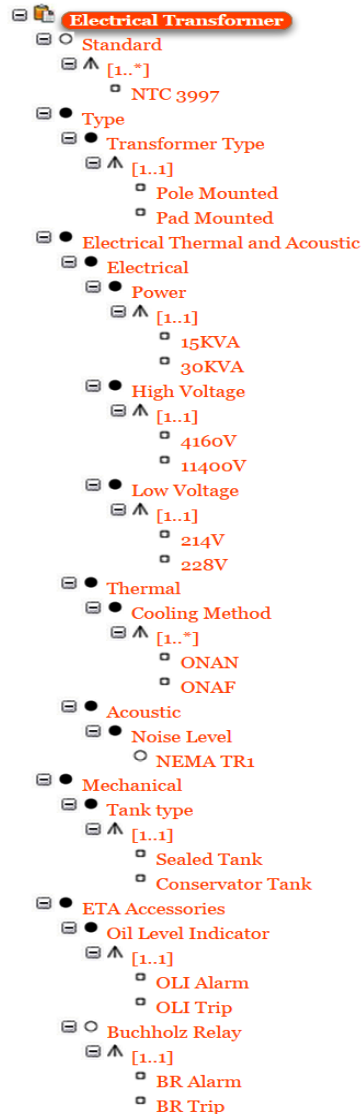
This model represents the existing products…

but we want to represent options to specify customized electrical transformers

Our First Attempt:
A Single Feature Model

Modelers

Domain Related Constraints

Standard

Standard Related Constraints

Additional constraints must be included to represent domain- and standards-related constraints

Electrical Transformer
- Standard
  - [1..*]
    - NTC 3997
- Type
  - Transformer Type
    - [1..1]
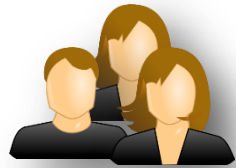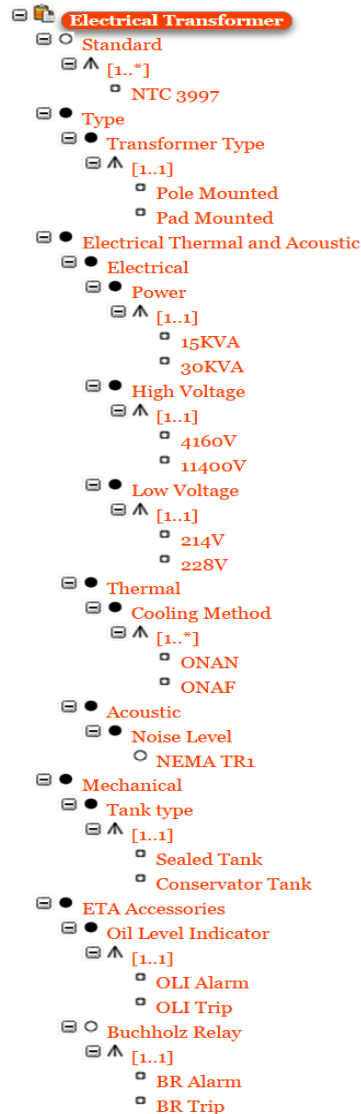   - Pole Mounted
      - Pad Mounted
- Electrical Thermal and Acoustic
  - Electrical
    - Power
      - [1..1]
        - 15KVA
        - 30KVA
    - High Voltage
      - [1..1]
        - 4160V
        - 11400V
    - Low Voltage
      - [1..1]
        - 214V
        - 228V
  - Thermal
    - Cooling Method
      - [1..*]
        - ONAN
        - ONAF
  - Acoustic
    - Noise Level
      - NEMA TR1
- Mechanical
  - Tank type
    - [1..1]
      - Sealed Tank
      - Conservator Tank
- ETA Accessories
  - Oil Level Indicator
    - [1..1]
      - OLI Alarm
      - OLI Trip
  - Buchholz Relay
    - [1..1]
      - BR Alarm
      - BR Trip

Our First Attempt:
A Single Feature Model

For a single family, with a single standard, we ended with +400 features and +120 cross-tree constraints

Our First Attempt:
A Single Feature Model
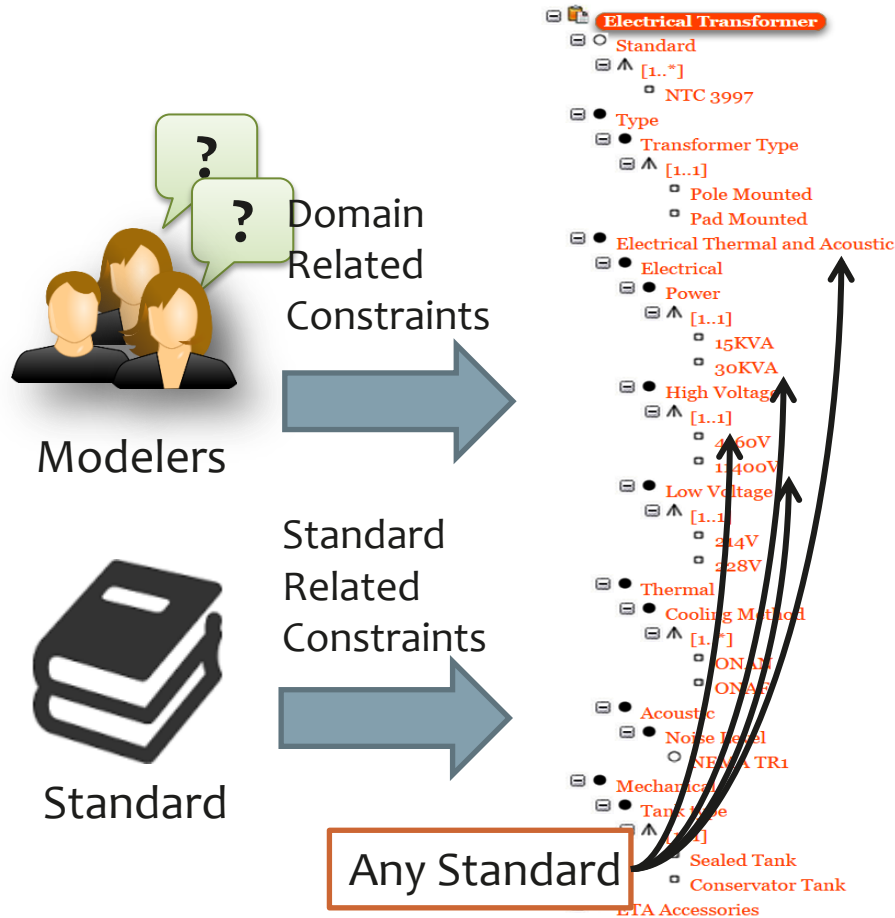
Because each standard imposes different constraints on branches, adding a new standard was a challenge

Trying to create a single feature model did not help us to define, review and analyze the features in each domain, the inter-domain constraints and the cross-cutting constraints defined by the diverse standards.

A Revisited Approach:
Using Multiple Feature Models
to represent the configuration options

A Revisited Approach

❶ Separation of Domains

❷ Model each domain

❸ Model inter-domain relationships

❹ Model standards

❺ Merge the Models

❻ Analysis and User Validation
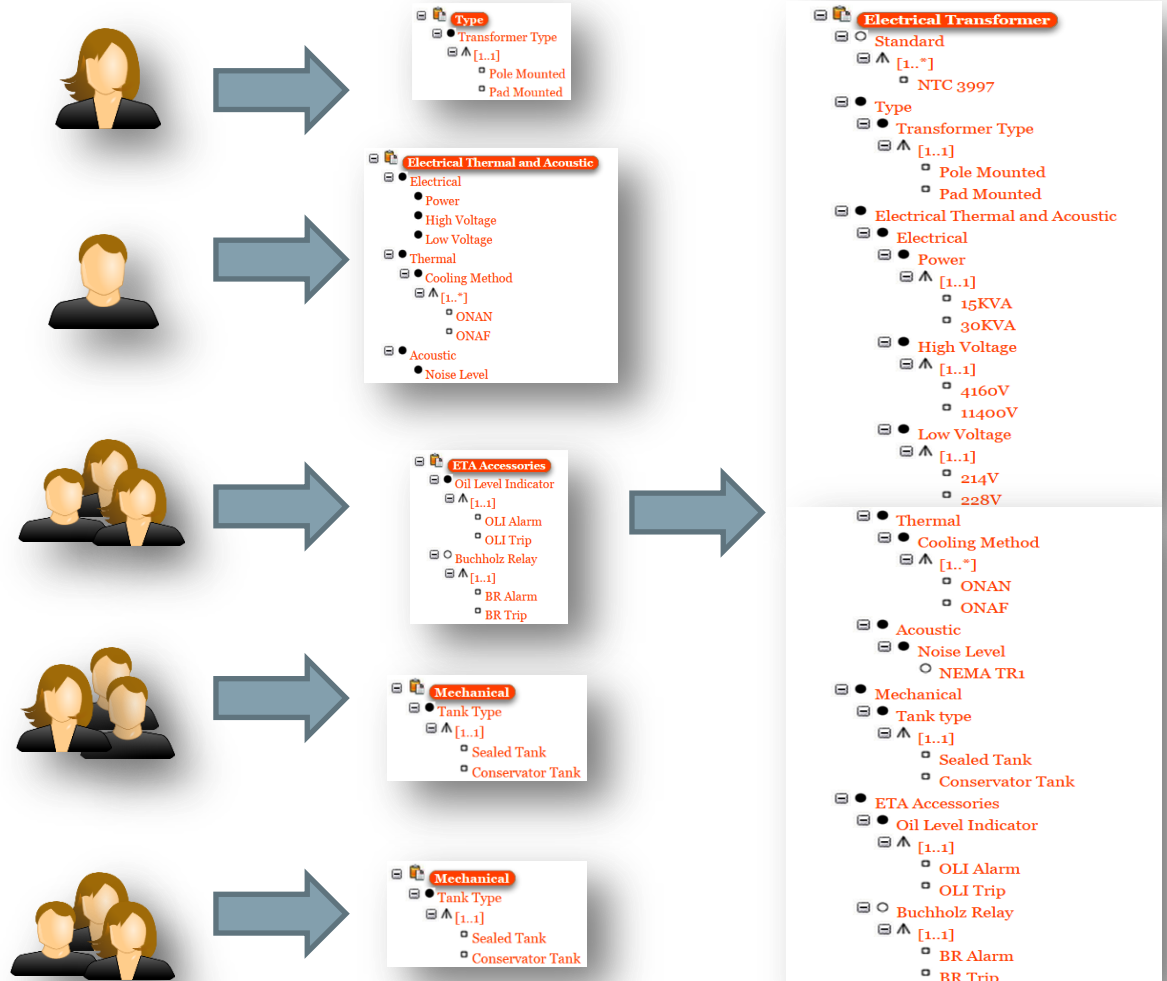
❶ Separation of Domains

System

Installation | ETA Accessories

Type | Electrical, Thermal and Acoustic

Mechanical

Mechanical Accessories
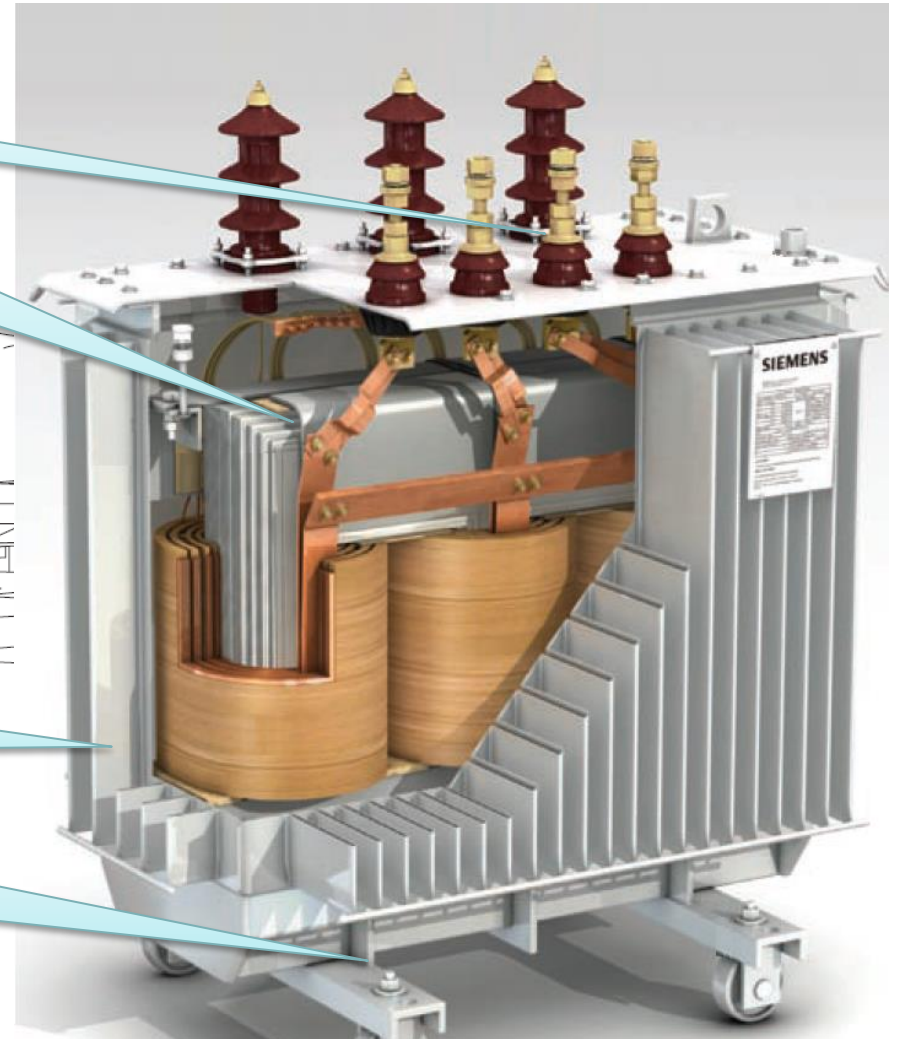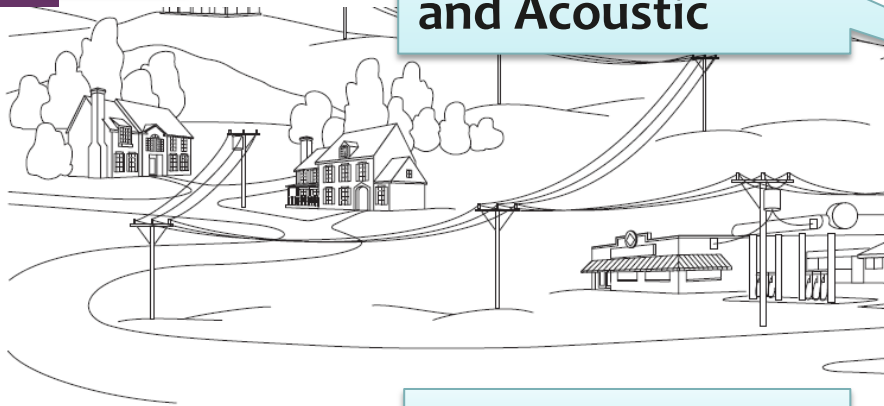
❷ Model each domain
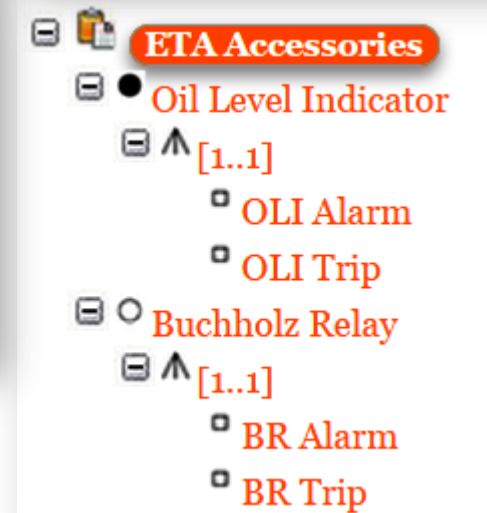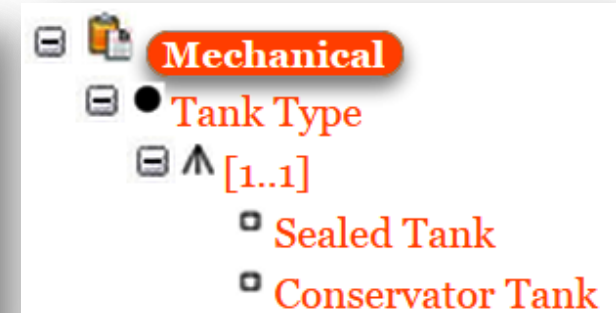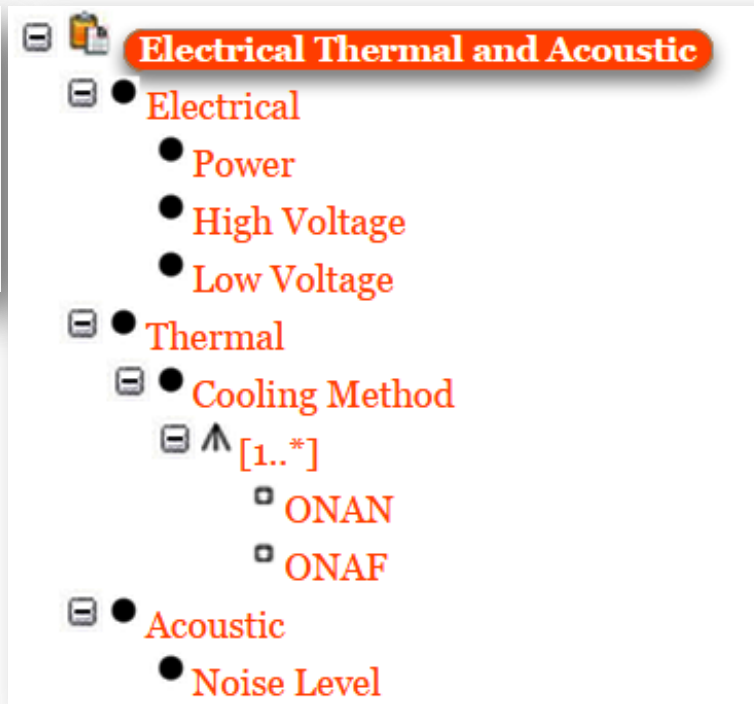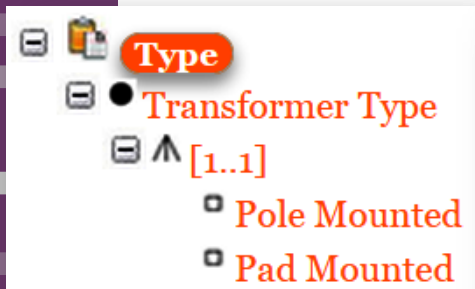
They were easier to build, understand and review by modelers

❸ Model Inter-domain relationships

Type
- Transformer Type
  - [1..1]
    - Pole Mounted
    - Pad Mounted

Electrical Thermal and Acoustic
- Electrical
  - Power
  - High Voltage
  - Low Voltage
- Thermal
  - Cooling Method
    - [1..*]
      - ONAN
      - ONAF
- Acoustic

Mechanical
- Tank Type
  - [1..1]
    - Sealed Tank
    - Conservator Tank

ETA Accessories
- Oil Level Indicator
  - [1..1]
    - OLI Alarm
    - OLI Trip
- Buchholz Relay
  - [1..1]
    - BR Alarm
    - BR Trip
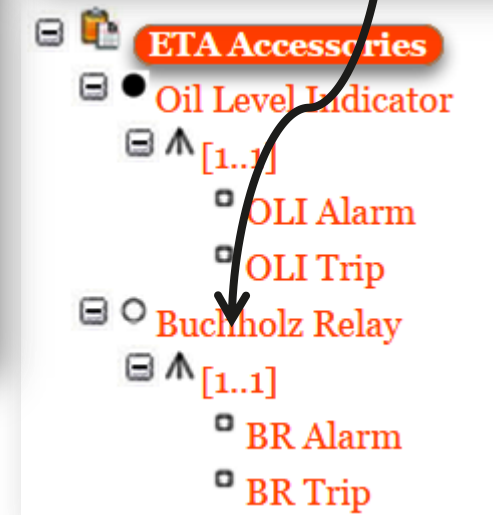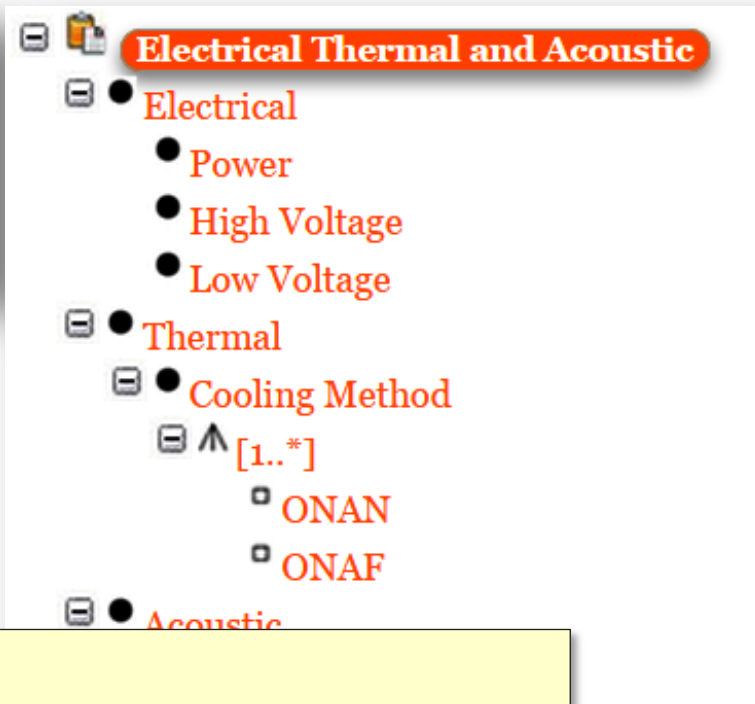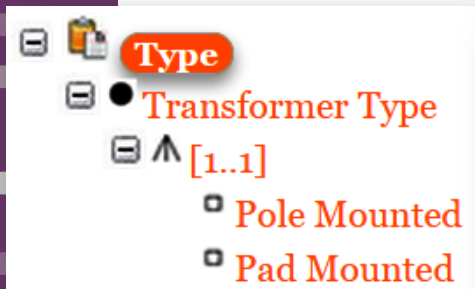
Sealed_tank => ~buchholz_relay

❹ Modeling of Standards

Type
- ● Transformer Type
  - ⋀ [1..1]
    - ▫ Pole Mounted
    - ▫ Pad Mounted

Electrical Thermal and Acoustic
- ● Electrical
  - ● Power
  - ● High Voltage
  - ● Low Voltage
- ● Thermal
  - ● Cooling Method
    - ⋀ [1..*]

Mechanical
- ● Tank Type
  - ⋀ [1..1]
    - ▫ Sealed Tank
    - ▫ Conservator Tank

ETA Accessories
- ● Oil Level Indicator
  - ⋀ [1..1]
    - ▫ OLI Alarm
    - ▫ OLI Trip
- ○ Buchholz Relay
  - ⋀ [1..1]
    - ▫ BR Alarm
    - ▫ BR Trip
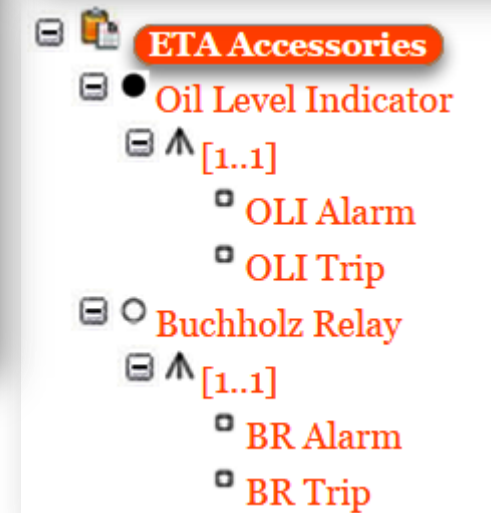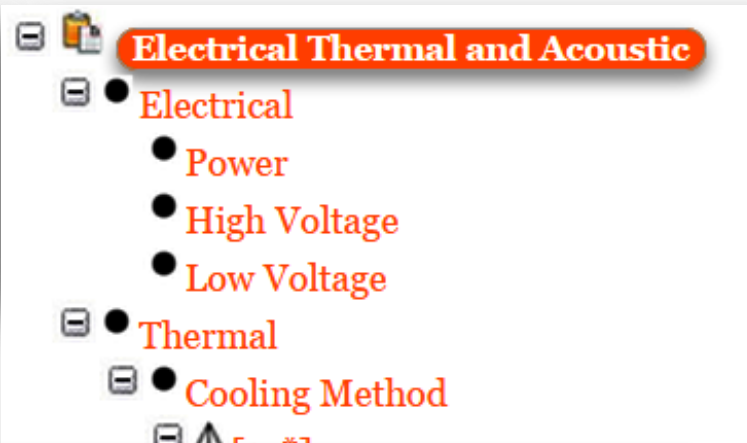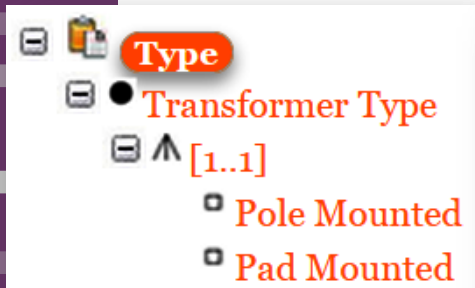
Ntc_3997 => pad_mounted
Ntc_3997 => Power = 15KVA ⋁ 30KVA
Ntc_3997 => High Voltage = 4160V ⋁ 11400V
Ntc_3997 => Low Voltage = 214V ⋁ 228V
Ntc_3997 => ONAN
Ntc_3997 => NEMA_TR1
Ntc_3997 => sealed_tank

❺ Merge Feature Models - Domains

❺ Merge Feature Models - Domains

Root (Electrical Transformer)

Type
- ● Transformer Type
  - ⋀ [1..1]
    - □ Pole Mounted
    - □ Pad Mounted

+

Electrical Thermal and Acoustic
- ● Electrical
  - ● Power
  - ● High Voltage
  - ● Low Voltage
- ● Thermal
  - Cooling Method
    - ⋀ [1..*]
      - □ ONAN
      - □ ONAF
- ● Acoustic
  - ● Noise Level

+

Mechanical
- ● Tank Type
  - ⋀ [1..1]
    - □ Sealed Tank
    - □ Conservator Tank

+

ETA Accessories
- ● Oil Level Indicator
  - ⋀ [1..1]
    - □ OLI Alarm
    - □ OLI Trip
- ○ Buchholz Relay
  - ⋀ [1..1]
    - □ BR Alarm
    - □ BR Trip
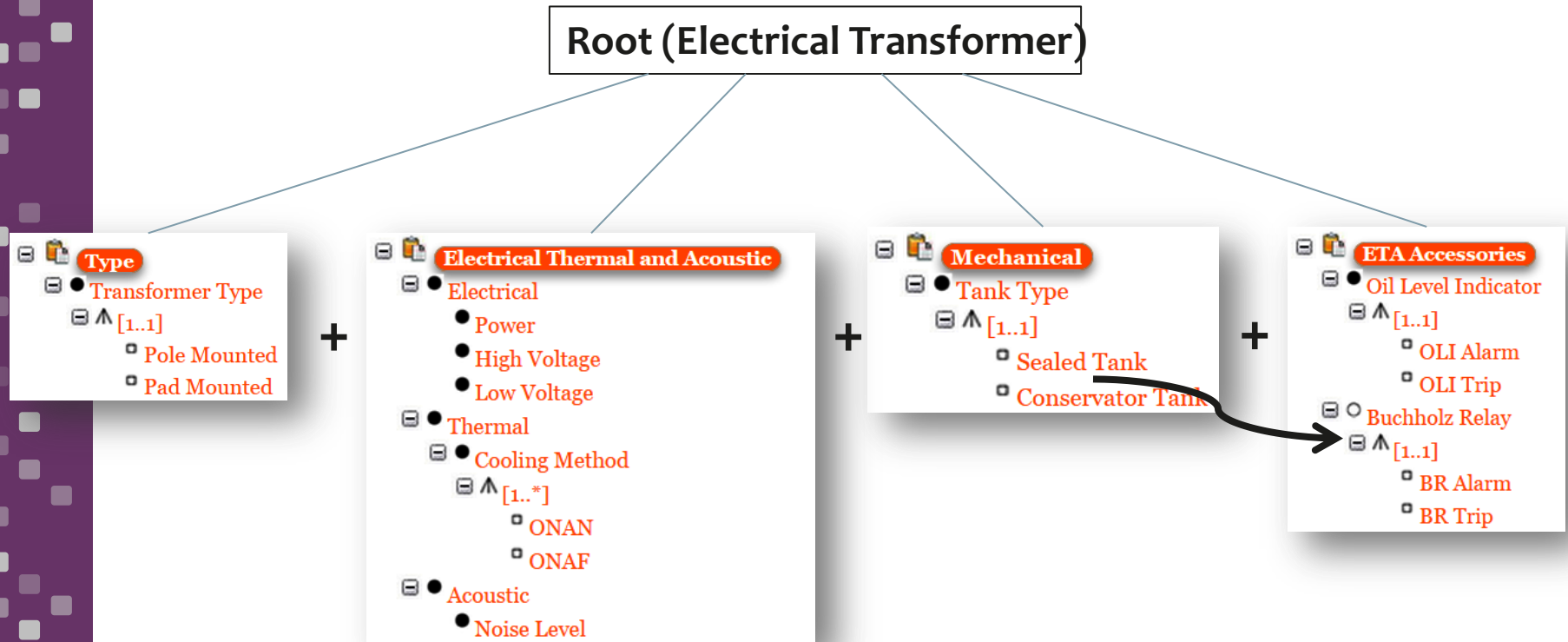
❺ Merge Feature Models - Standards

Ntc_3997
=> pad_mounted
=> Power = 15KVA ∨ 30KVA
=> High Voltage = 4160V ∨ 11400V
=> Low Voltage = 214V ∨ 228V
=> ONAN
=> NEMA_TR1
=> sealed_tank

+
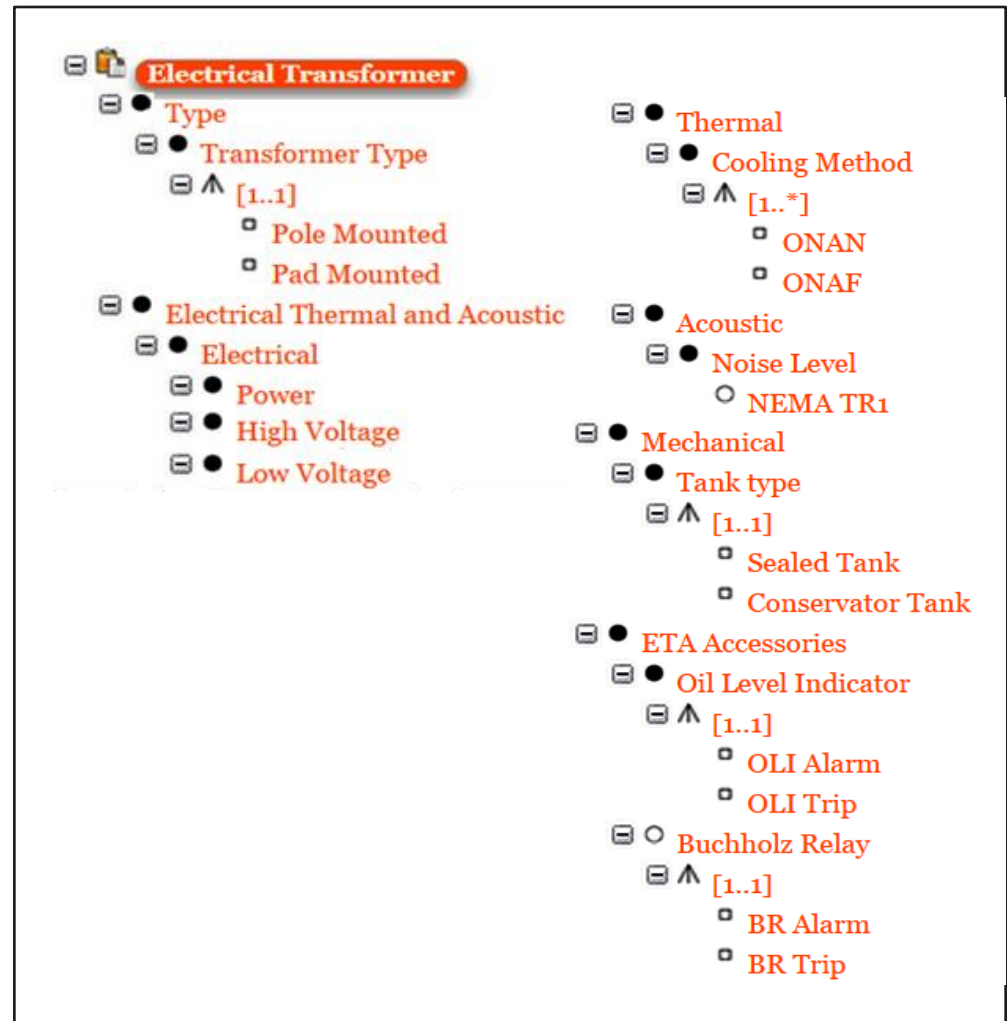
❺ Merge Feature Models - Standards

Add an standard

Ntc_3997
 => pad_mounted
 => Power = 15KVA ∨ 30KVA
 => High Voltage = 4160V ∨ 11400V
 => Low Voltage = 214V ∨ 228V
 => ONAN
 => NEMA_TR1
 => sealed_tank

+

➎ Merge Feature Models - Standards

Introduce constraints

Ntc_3997
    => pad_mounted
    => Power = 15KVA ∨ 30KVA
    => High Voltage = 4160V ∨ 11400V
    => Low Voltage = 214V ∨ 228V
    => ONAN
    => NEMA_TR1
    => sealed_tank

+

Electrical Transformer
- Type
  - Transformer Type
    - [1..1]
      - Pole Mounted
      - Pad Mounted
- Electrical Thermal and Acoustic
  - Electrical
    - Power
    - High Voltage
    - Low Voltage

- Thermal
  - Cooling Method
    - [1..*]
      - ONAN
      - ONAF
  - Acoustic
    - Noise Level
      - NEMA TR1
- Mechanical
  - Tank type
    - [1..1]
      - Sealed Tank
      - Conservator Tank
- ETA Accessories
  - Oil Level Indicator
    - [1..1]
      - OLI Alarm
      - OLI Trip
  - Buchholz Relay
    - [1..1]
      - BR Alarm
      - BR Trip
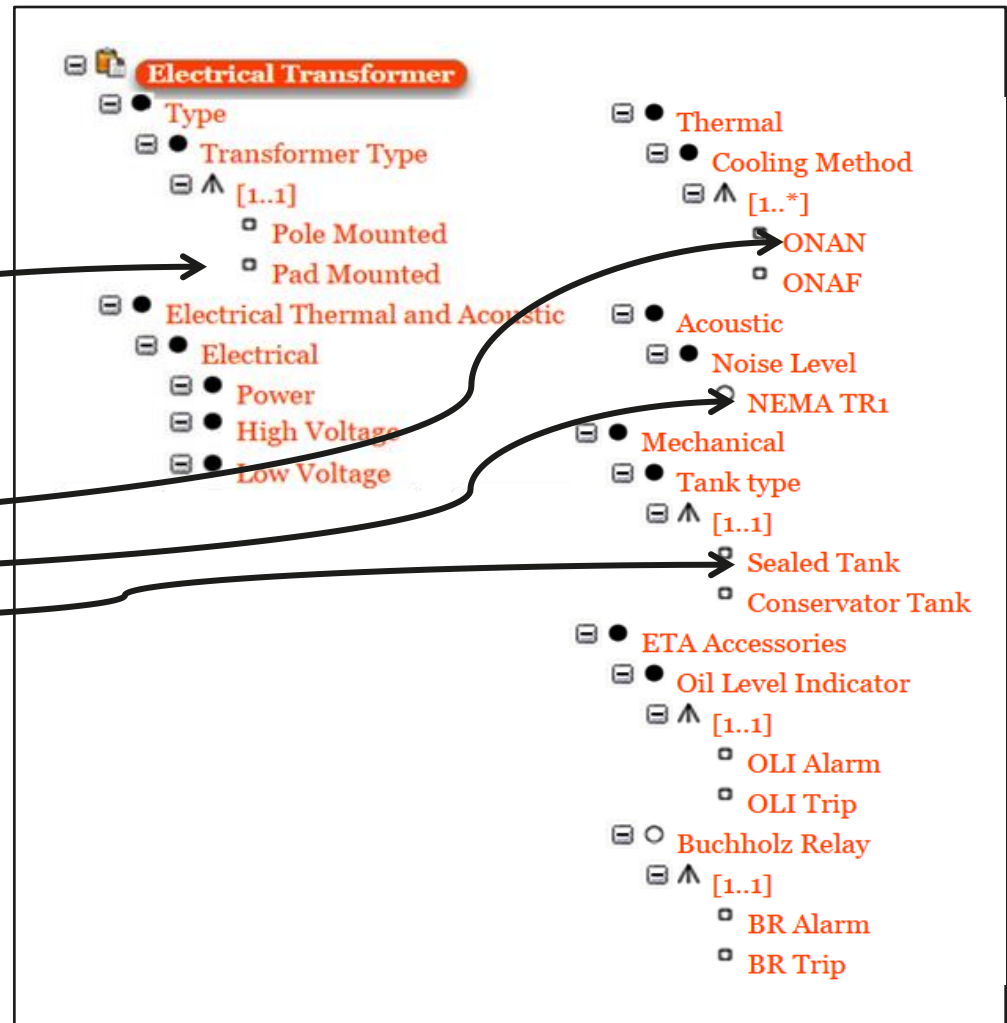
❺ Merge Feature Models - Standards

Add values and constraints

Ntc_3997
    => pad_mounted
    => Power = 15KVA ⋁ 30KVA
    => High Voltage = 4160V ⋁ 11400V
    => Low Voltage = 214V ⋁ 228V
    => ONAN
    => NEMA_TR1
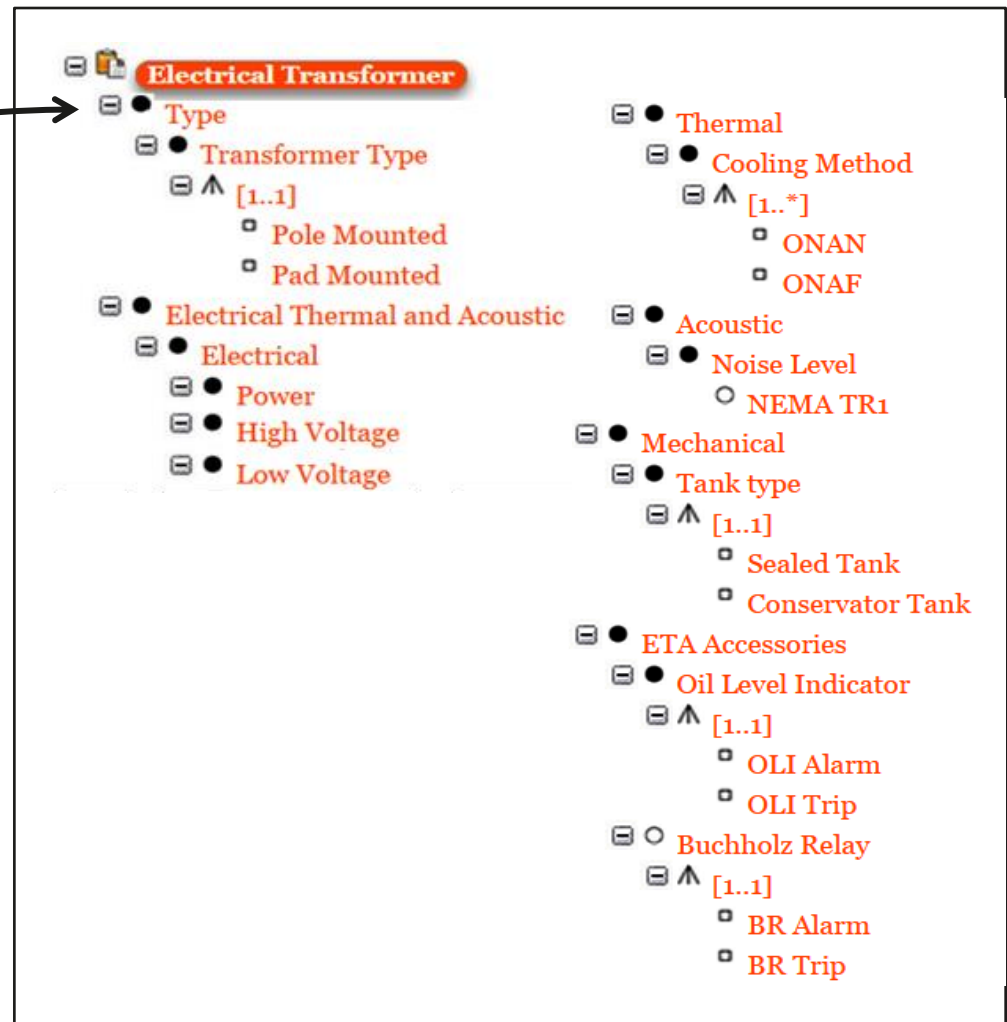   => sealed_tank

+

- **Electrical Transformer**
  - Type
    - Transformer Type
      - [1..1]
        - Pole Mounted
        - Pad Mounted
  - Electrical Thermal and Acoustic
    - Electrical
      - Power
      - High Voltage
      - Low Voltage
    - Thermal
      - Cooling Method
        - [1..*]
          - ONAN
          - ONAF
    - Acoustic
      - Noise Level
        - NEMA TR1
  - Mechanical
    - Tank type
      - [1..1]
        - Sealed Tank
        - Conservator Tank
  - ETA Accessories
    - Oil Level Indicator
      - [1..1]
        - OLI Alarm
        - OLI Trip
    - Buchholz Relay
      - [1..1]
        - BR Alarm
        - BR Trip

❺ Merge Feature Models - Standards

Electrical Transformer
- ○ Standard
  - ⋀ [1..*]
    - NTC 3997
- ● Type
  - ● Transformer Type
    - ⋀ [1..1]
      - Pole Mounted
      - Pad Mounted
- ● Electrical Thermal and Acoustic
  - ● Electrical
    - ● Power
      - ⋀ [1..1]
        - 15KVA
        - 30KVA
    - ● High Voltage
      - ⋀ [1..1]
        - 4160V
        - 11400V
    - ● Low Voltage
      - ⋀ [1..1]
        - 214V
        - 228V
- ● Thermal
  - ● Cooling Method
    - ⋀ [1..*]
      - ONAN
      - ONAF
- ● Acoustic
  - ● Noise Level
    - ○ NEMA TR1
- ● Mechanical
  - ● Tank type
    - ⋀ [1..1]
      - Sealed Tank
      - Conservator Tank
- ● ETA Accessories
  - ● Oil Level Indicator
    - ⋀ [1..1]
      - OLI Alarm
      - OLI Trip
  - ○ Buchholz Relay
    - ⋀ [1..1]
      - BR Alarm
      - BR Trip

❻ Analysis and User Validation

Continuous Validation/Testing of the Models

– Peer-review

– Automated analysis

– Tests using products from the existing catalogs
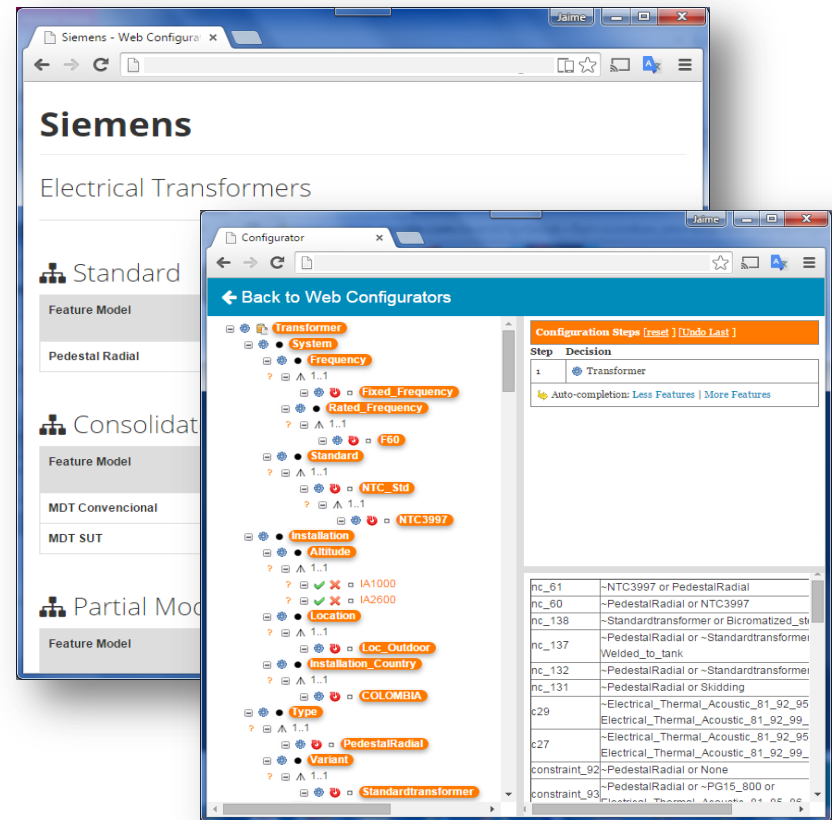
Tool Support

Our tools use/extend SPLOT...

- – Create Feature Models from standards
- – Merge Feature Models
- – Analyze single and merged Feature Models

- – Configure multiple feature models
- – Perform tests and validations

http://www.splot-research.org/

Some Lessons Learned and Conclusions

Lesson Learned

❶ **Modeling**

– Using a single feature model is tough

– Multiple feature models facilitates the modeling

– The separation of domains is an iterative process

– Each standard can be modeled independently

– Incremental modeling facilitates the work

domains : 10 – 123 features

standards: 69 – 71 features

Lesson Learned

❷ **Models Validation**

– Incremental modeling → Continuous Testing
– We can test the models using product catalogs and reviews

❸ **Tools**

– Existing tools has limited support to multiple FMs
– Partial configurations can be used to lead the process

❹ **Impact on other Processes**

– This allowed engineers to define and enforce standards in the company

Questions?

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