USING AN ENRICH SEMANTIC IN DESIGN STRUCTURE MATRIX (DSM) TO GENERATE LESS UNCERTAIN CONCEPTS

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Keywords: multi-physics, collaborative design, DSM

1. INTRODUCTION

In the context of new product development, highly constrained multi-disciplinary systems are difficult to design and generally lead to a non-optimal but acceptable solution (Seepersad, 2008). Such products are interdependent and imply the collaboration of designers from different design departments who have to take into account various points-of-view.

Collaboration starts early in the definition and choice of concepts. Concept analysis is thus a key point in product design. Existing tools only allow the analysis of concepts regarding the component point-of-view. Our industrial analysis shows that several collaborative problems are located outside component design. For instance, some incompatibilities appear during the integration step. These incompatibilities can be avoided by an analysis of interfaces between design departments.

This article describe our approach, based on enrich semantic in DSM, for the integration of such multiphysic interfaces early in the choice of concepts.

2. PROBLEM STATEMENT

In view of customers growing demands, products are becoming more complex in terms of the number of functions integrated. This multifunctional integration has had a significant impact on product design: the increased complexity has increased the number of design parameters, constraints and objectives (Gomes, 2006). In collaborative design, this high number of variables leads to complex dependencies between design departments.

Design can be described as a value definition process for each design parameter representing a concept. The collaboration between design departments consists of fixing common values for the shared design parameters. In most cases, due to their own constraints and performance requirements, design departments desire different values of common design parameters. Therefore the collaboration leads to design conflicts and to the necessity to find compromises.

This research study is conducted in collaboration with Schlumberger, worldwide leader in petroleum services. The recent development of onboard electronic cards is an example of this multiphysics problem. An electronic card must be integrated within a box attached to a main mechanical component. The whole assembly goes into in a tube (with a diameter limited by the drill). Therefore, dimensions of the system are highly correlated and highly impact on the design. In order to develop this product the expertise of three design departments is needed (mechanical, electrical and packaging). Every department optimizes their design to maximize performances, for example the number of electronic card by product foot length. In this case, 18 months after the concept choice, the project failed due to incapability to manage one design parameter, requiring the concept to be changed.

The current approach is made through the choice of concept and then the management of multiphysic dependencies. This approach is too limiting for complex problems. As interfaces between design departments influence product performances, they should be integrated as a variable in concept choice.

3. LITERATURE REVIEW

The research literature is mainly addressing previous issues with the usage of Design Structure Matrix (DSM). Three main design stages are addressing the choice of concept: concept generation, concept analysis and concept evaluation. In the scope of this review only concept analysis is exposed.

Concept analysis is a preliminary work for the choice of "best" concepts. The aim of this stage is to identify usable information to design concepts. The usage of DSM permits identification of the potential inconsistency of solutions.

Hellenbrand et al. (2008) propose a simple approach that combines different component alternatives in order to list consistent concepts. The clustering is done through the filling of a DSM by engineers. The only information available for designers is the existence or not of the compatibility between two components. This is presented by a "_" or a "X" square in the matrix.

Wyatt et al. (2008) propose to define inconsistency of concepts. They define an "Architecture Schema" based on an ontology where "components are linked to component types and to connection types". The inconsistency is defined as the impossibility to assemble components.

The main lack of the literature is that all approaches are addressing only the component point-of-view. Physical connections are defined as a possibility or impossibility to assemble two components. This implies that technical solutions to achieve physical connections are not taken into account as design parameters in the concept choice. Physical connections influence performances and they have to be taken into account at the same level as components.

4. OUR GLOBAL APPROACH: THE AID METHOD

The goal of our global approach is to map design department point-of-views, architecture alternatives, functional needs and expected performances. With this process, our approach aims at helping designers to model their collaborations with other design departments and to assess their impacts on the final product. The proposed AID (Analysis, Identification, Design) matrix-based method is organized into three steps:

1. *Analysis of multiphysic interfaces*: The objective of this first step is to identify multiphysic interfaces and to quantify their influences. DSM, DMM and QFD matrices are introduced.
2. *Identification of difficult interactions*: The aim of this second step is to identify difficulties in previous define interfaces through the cross of metrics (indicators and heuristics) extracted from MDM (DSM - DMM) and QFD matrices previously filled.
3. *Definition of resolution process*: This third step brings information from a data model. This data model is built on multiphysic aspects: for any physical connection types a data sheet is generated with key design parameters controlled by design departments or shared by them. Information such as dimensioning parameters, objective targets, and best practices for the optimization is also included.

Finally, the AID method is able to evaluate design alternatives (by crossing DMM and QFD information) and to generate better concepts (by correlation between DSM and QFD) which are less confrontational for design departments. Concepts are ranked to let the team project focus on the best products (mixing MDM and QFD data).

This article will focus on the analysis of multiphysic interfaces through the use of DSM. The proposed enrich semantic will enable connections to the data model (not developed here). Thus, our research aims to improve knowledge in the design dependencies through the model of designer collaboration with other design departments early in the choice of concept.

5. DSM: AN EXPERIMENTAL EXAMPLE

This approach has been experimented on an industrial application which aims to develop onboard electronic cards under the scope of a project. The previous card developments were not able to achieve environmental constraints: high pressure, high temperature under shock and vibrations are required. The goals of our application were to propose new concepts as design orientations to achieve project requirements.

Our AID method has been applied during a three day workshop organized by our industrial supporter with the contribution of one of his suppliers. The team was composed by eight engineers; respectively five from the supporter and three from the supplier. The three day organization was deployed as:

- On the first day, the design team expressed problem settings and undertook a creativity session to generate possible concepts, finally the design team sponsor was shown the five concepts they imagined.
- On the second day, we listed expected performances and failure modes, and then MDM and QFD empty matrices were created.
- On the third day, engineers evaluated design solutions regarding every performance. Due to the simplicity of our approach (Holley, 2008), all evaluations were completed in only 4 hours. In total, the method evaluated two hundred design alternatives.

Analysis starts with an empty DSM matrix and the design department's engineers. The person responsible for the deployment of the tool first lists with designers all possible assemblies between technical solutions. This process can be done through the description of imagined concepts as shown in Figure 1 (see concept number 1 and 2) or through the description of possible assembly between two design solutions. The description is done through the designation of physical connection type (a taxonomy is proposed in the table noted A). Then the tool responsible is filling DSM matrix as in Figure 1.

Figure 1 represents such a filled DSM matrix used to represent physical connections between possible architectures. In this example, the onboard electronic card is composed by two modules: a chassis and a box which can be made by respectively seven and four alternatives called design solutions. Design solutions are described by name in the second row and the second column (This matrix is unidirectional, and thus symmetric). The blue row and columns represent the design control of the mechanical design department and the green ones the packaging design department.

For instance, in Figure 1, the physical connection between the denoted 'I' chassis and the denoted 'Basin' box (square crossing the two design solutions) which are described by the concept noted '1' is an 'E' physical connection. This 'E' is related to Elastomer in table A (the same figure). Concept '1' represents this assembly and the physical connection (the red parts are elastomer). An empty square means no compatibility between two design solutions. A square with two letters describes an alternative physical connection.

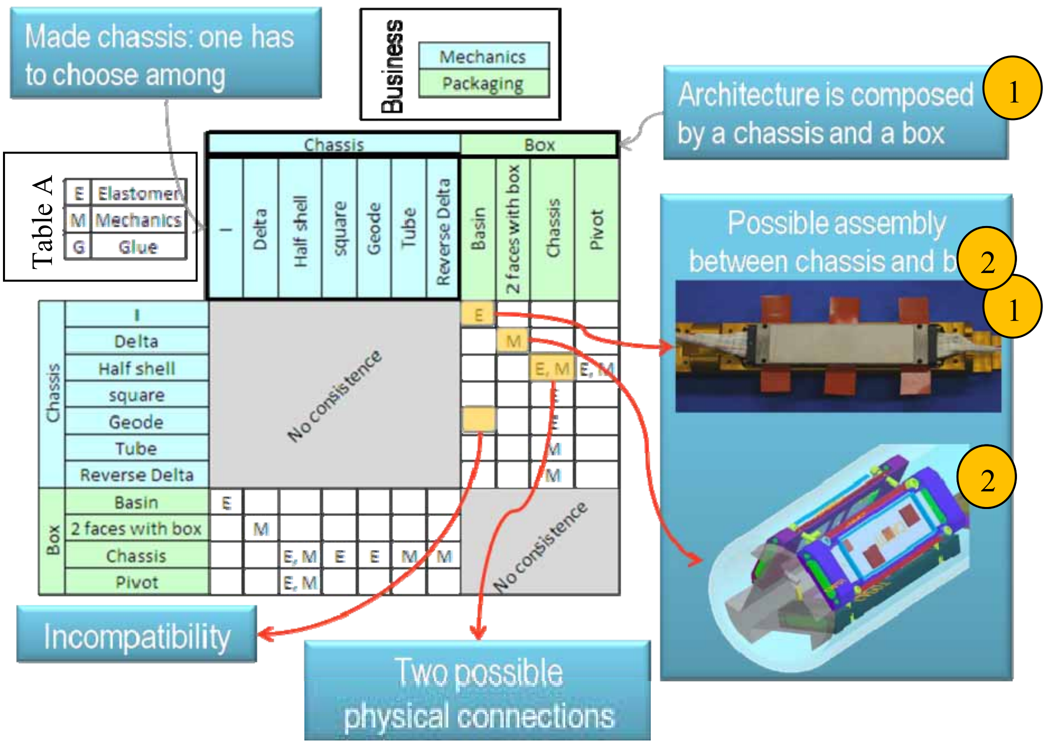

Figure 1. An illustrated example of the usage of a DSM

A valid concept is defined as a combination of a technical solution for a module. Each module is needed to make a valid solution (In our example, one design solution for chassis and one design solution for box). Valid concepts are extracted from the DSM using an algorithm going through all squares. For instance, a concept cannot be composed by a chassis called 'geode' and a box called 'pivot' because the crossing square is empty.

Every physical connection type (as for instance Elastomer) is linked to a data model built on multiphysic design aspect: key design parameters controlled by design departments or shared by them, dimensioning parameters, objective targets, and best practices for the optimization are also included. This aspect of the work will not be developed in this article.

6. CONCLUSIONS

This paper presents our approach to map physical connections in product architectures. Based on a taxonomy of physical connections, the design team can define physical relations between two design solutions. This improvement brought early in concept enables the design team to choose from among architectures and to reduce constraints in product design.

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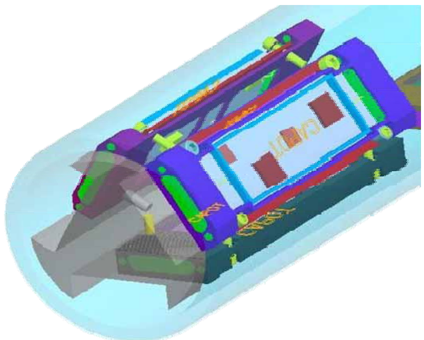
Schlumberger
CENTRALE PARIS

An industrial context: Schlumberger

- Worldwide leader oilfield providers designing their own products for its service delivery.
- Highly constraint environment (still increasing)
  - High pressure,
  - High temperature,
  - …
- Multi-physic products
  - Mechanic,
  - Electronic,
  - Software,
  - Physic.



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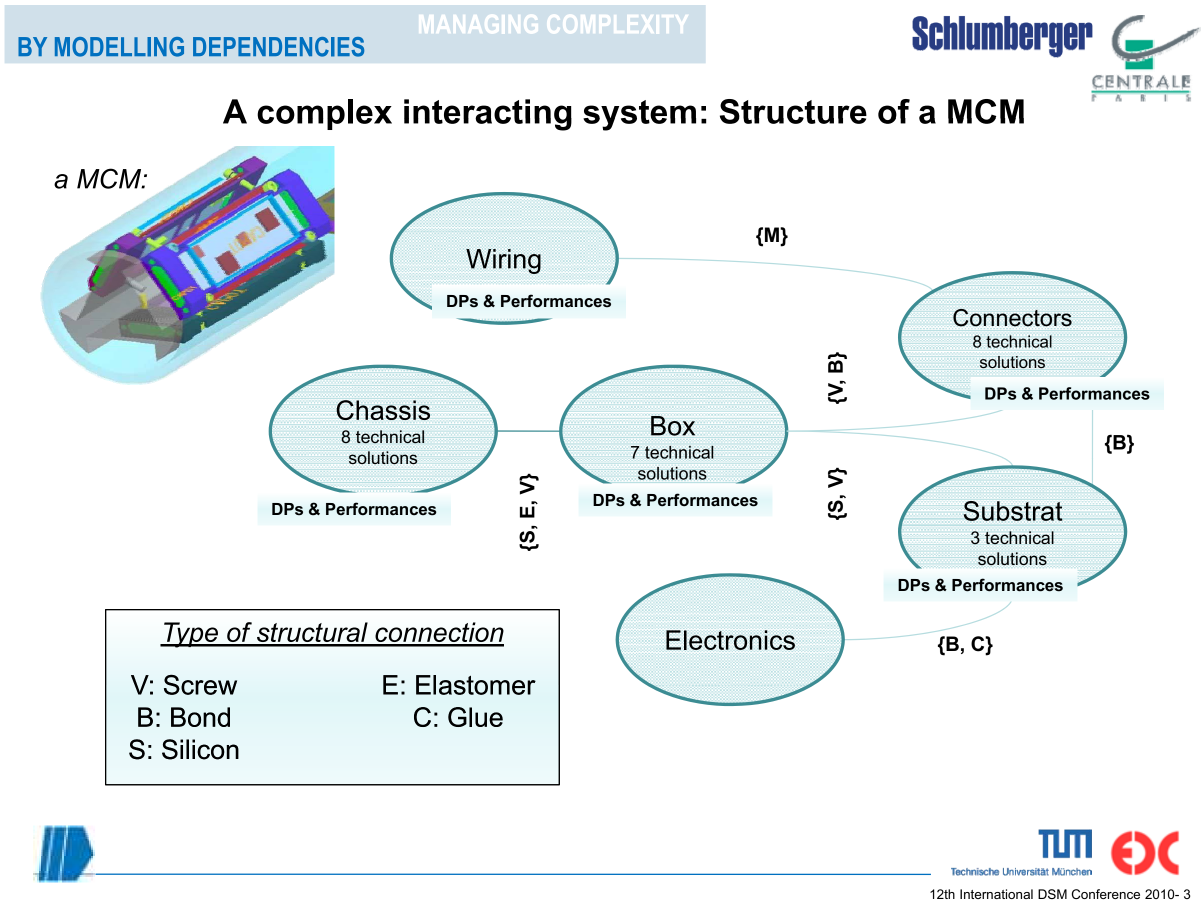
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A complex interacting system: Structure of a MCM
a MCM:
Wiring
DPs & Performances
{M}
Connectors
8 technical solutions
DPs & Performances
{V, B}
Chassis
8 technical solutions
DPs & Performances
Box
7 technical solutions
DPs & Performances
{S, E, V}
{S, V}
{B}
Substrat
3 technical solutions
DPs & Performances
Electronics
{B, C}
Type of structural connection
V: Screw
E: Elastomer
B: Bond
C: Glue
S: Silicon
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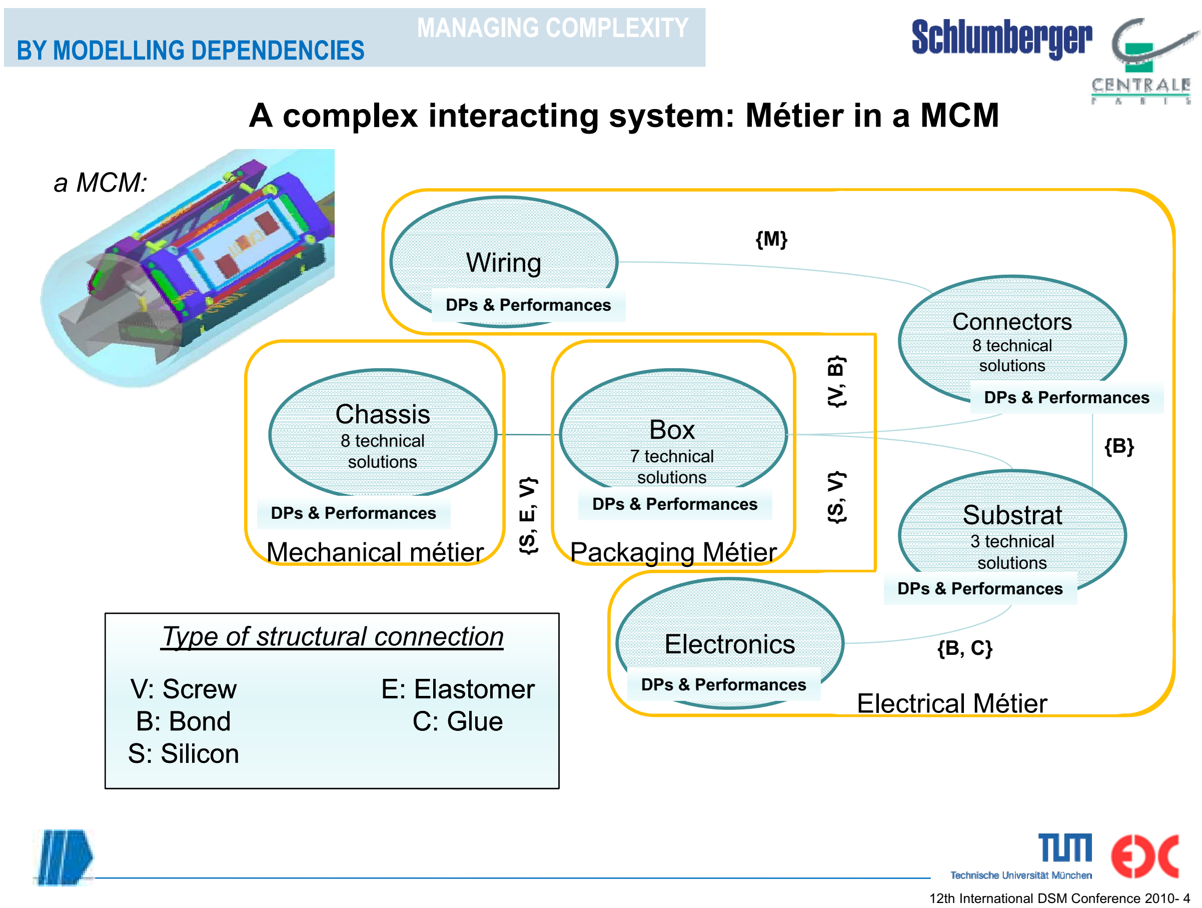
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A complex interacting system: Métier in a MCM
a MCM:
Wiring
DPs & Performances
{M}
Connectors
8 technical solutions
DPs & Performances
{V, B}
Chassis
8 technical solutions
DPs & Performances
Mechanical métier
Box
7 technical solutions
DPs & Performances
Packaging Métier
{S, E, V}
{S, V}
{B}
Substrat
3 technical solutions
DPs & Performances
Electronics
DPs & Performances
{B, C}
Electrical Métier
Type of structural connection
V: Screw
E: Elastomer
B: Bond
C: Glue
S: Silicon
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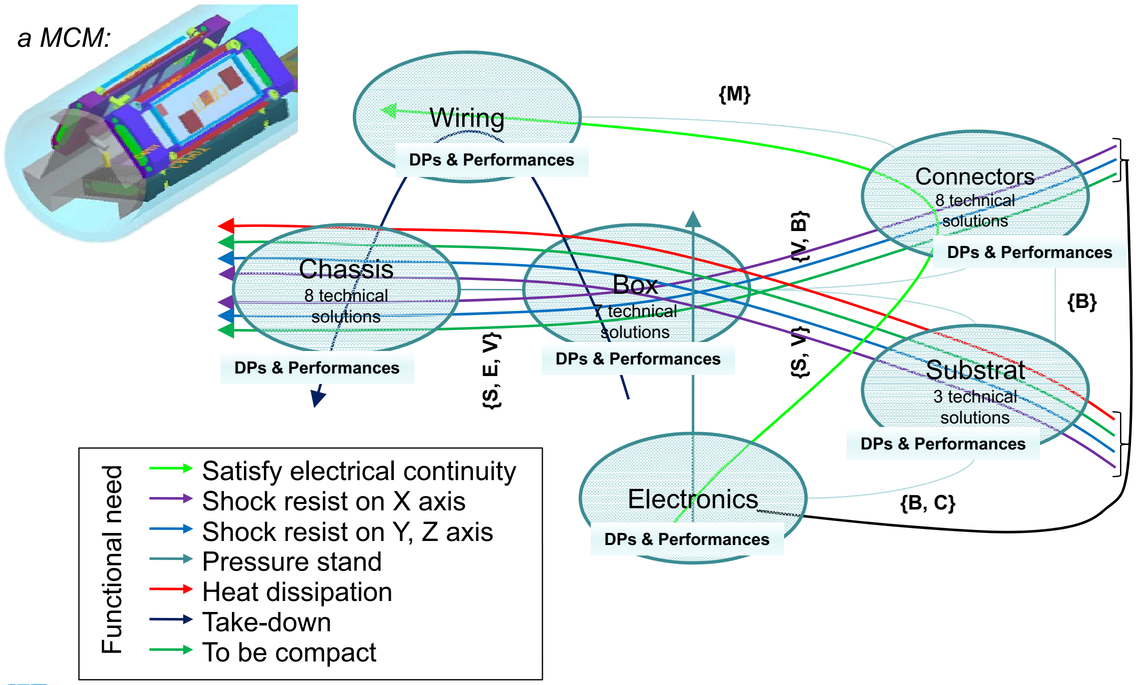
A complex interacting system: Functions of a MCM



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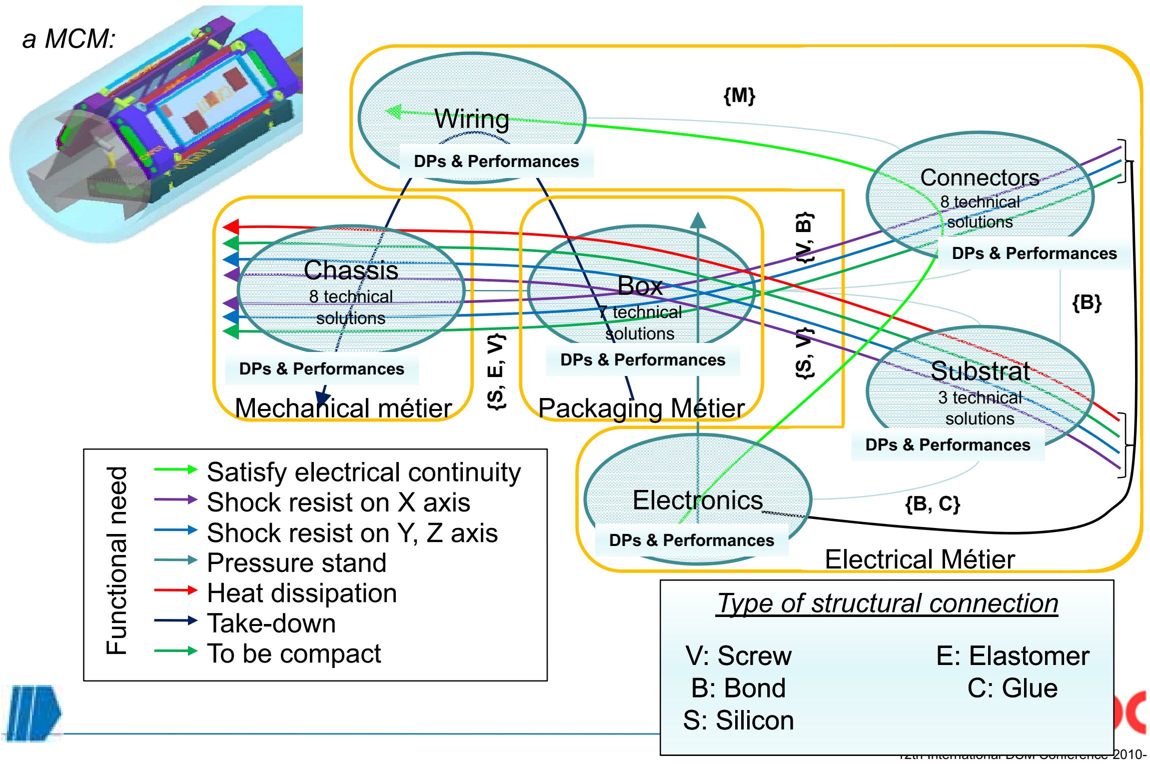
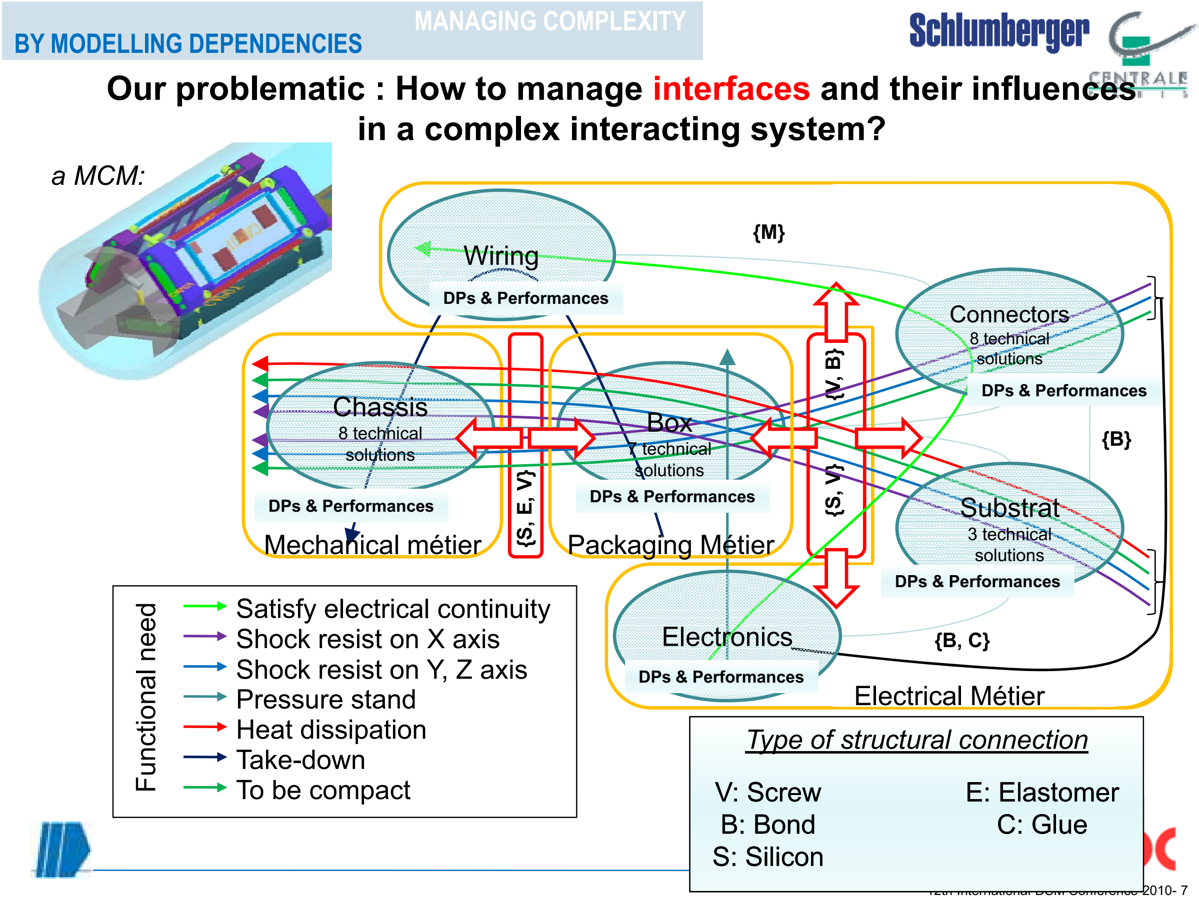
A complex interacting system: Overall of a MCM





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Our problematic : How to manage interfaces and their influences in a complex interacting system?
a MCM:
Wiring
DPs & Performances
{M}
Connectors
8 technical solutions
DPs & Performances
Chassis
8 technical solutions
DPs & Performances
Mechanical métier
{S, E, V}
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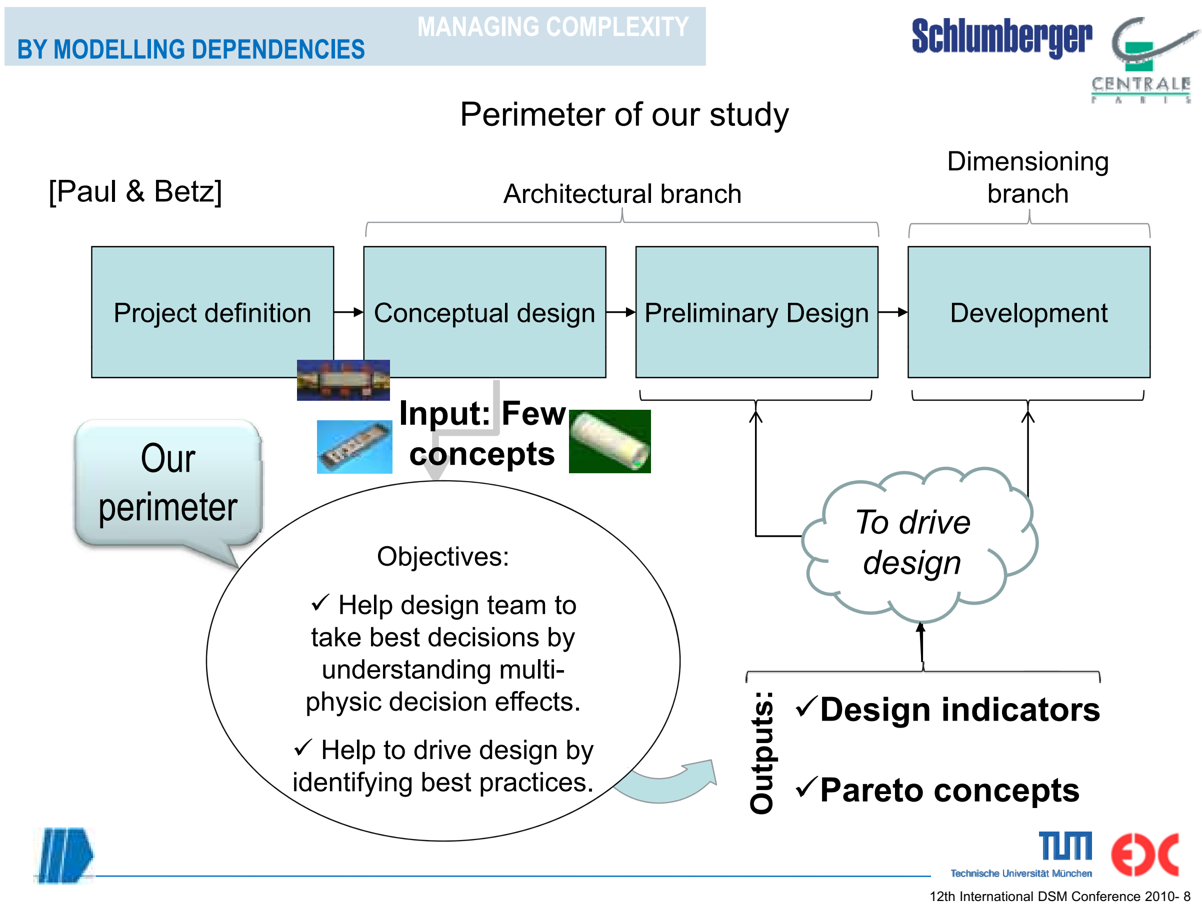
{V, B}
{S, V}
{B}
Substrat
3 technical solutions
DPs & Performances
Electronics
DPs & Performances
{B, C}
Electrical Métier
Functional need
Satisfy electrical continuity
Shock resist on X axis
Shock resist on Y, Z axis
Pressure stand
Heat dissipation
Take-down
To be compact
Type of structural connection
V: Screw
B: Bond
S: Silicon
E: Elastomer
C: Glue
2010- 7



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Perimeter of our study
[Paul & Betz]
Architectural branch
Dimensioning branch
Project definition
Conceptual design
Preliminary Design
Development
Input: Few concepts
Our perimeter
Objectives:
✓ Help design team to take best decisions by understanding multi-physic decision effects.
✓ Help to drive design by identifying best practices.
To drive design
Outputs:
✓Design indicators
✓Pareto concepts
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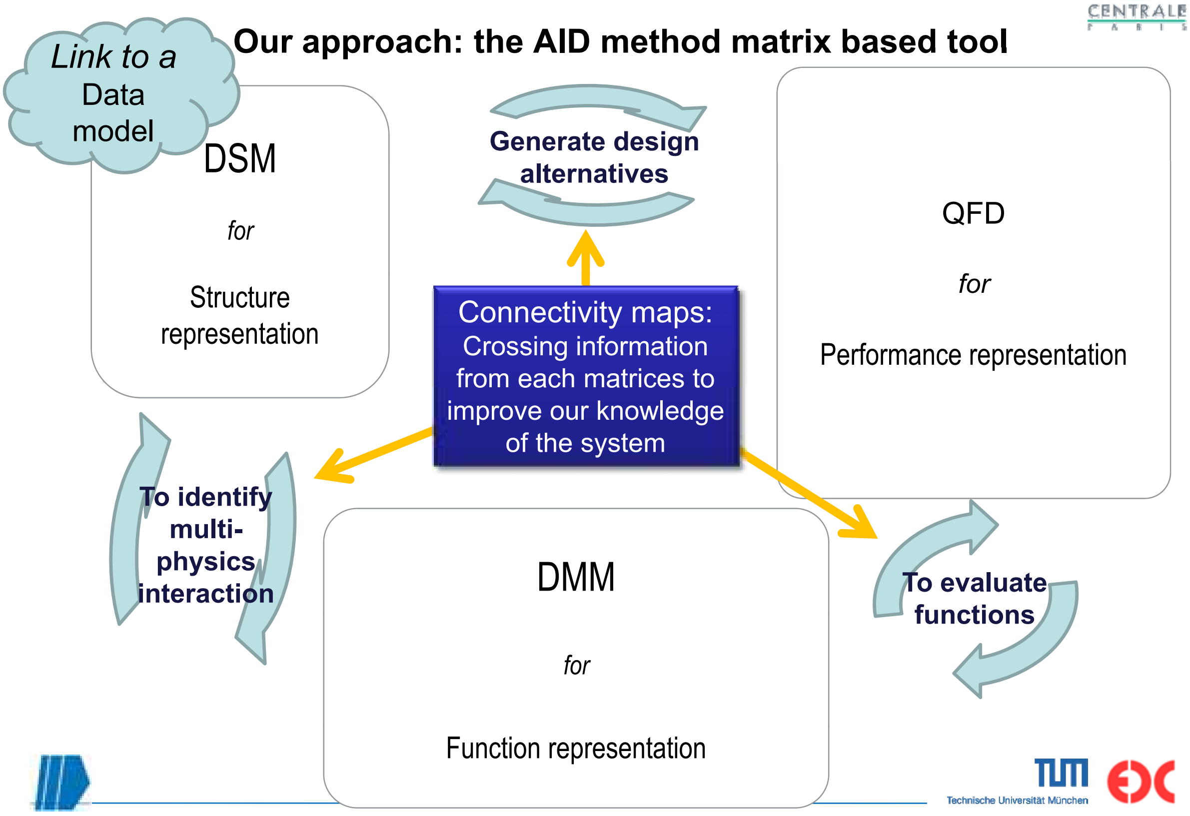
Our approach: the AID method matrix based tool

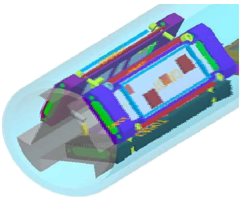


Our approach: the AID method in a three step process

1. **Analysis of multi-physic concepts: Gathering data**
   1. The identification of interfaces is done through the DSM (for structure) and DMM matrices (for structure-function relationship).
   2. The influence of these interfaces is analyzed by a QFD (for correlation with performances).
2. **Identification of difficult interfaces: Data treatment**
   1. Proposal for characterization of interfaces.
   2. The extraction and the passing of indicators from the previous matrices will help highlight certain difficulties.
3. **Definition of resolution process: Selecting best process**
   1. The key multi-physic parameters.
   2. Elements to take into account for dimensioning.
   3. The best process for optimization.

Focus of the article: DSM for structure representation

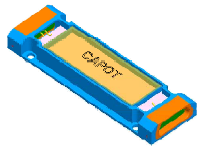
- Definitions:
  - Structure representation means the description of all the possible architecture to achieve the product.
  - Module describes a part need in the product architecture.
  - Technical solution is a possibility to achieve a module.
  - Interaction describes the physical connection in the assembly of two technical solutions together.



An architecture

Composed by:

✓A collar
✓A chassis
✓A box
✓Connectors
✓Substrate
✓Electronics

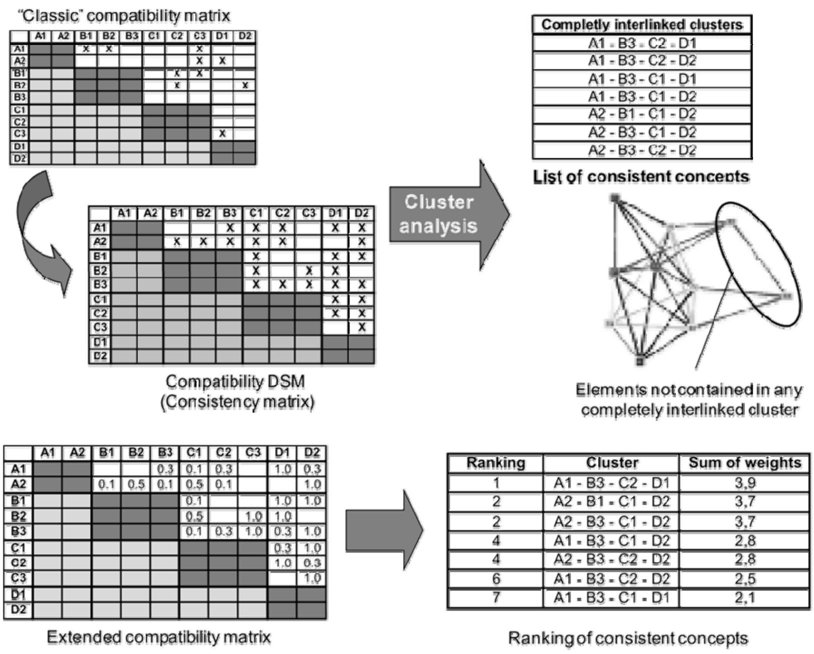


A technical solution for the box and connectors

Our objective
✓Describes all architecture alternative, including technical solutions and interfaces to assemble them.

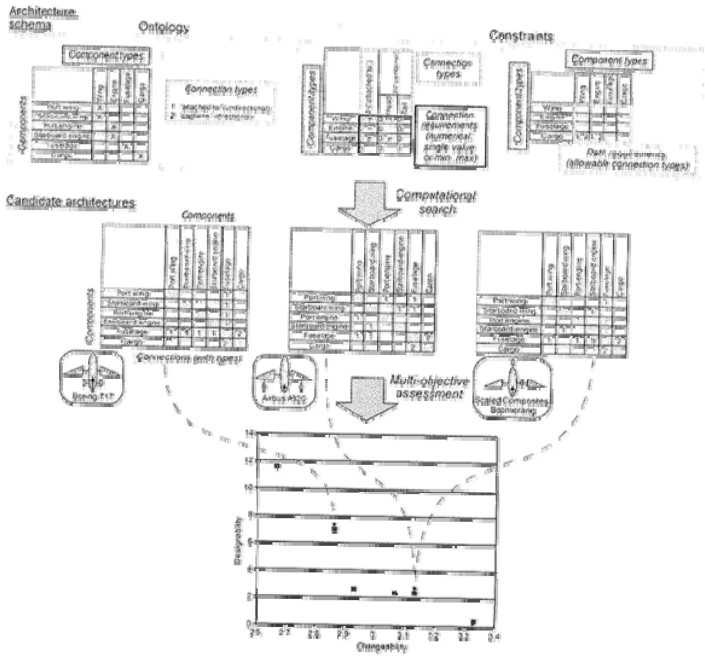
Literature review: Compatibility matrix

Hellenbrand, Lindemann, DSM, 2008



Literature review: Inconsistency

Wyatt, Wynn, Clarkson,
DSM, 2008

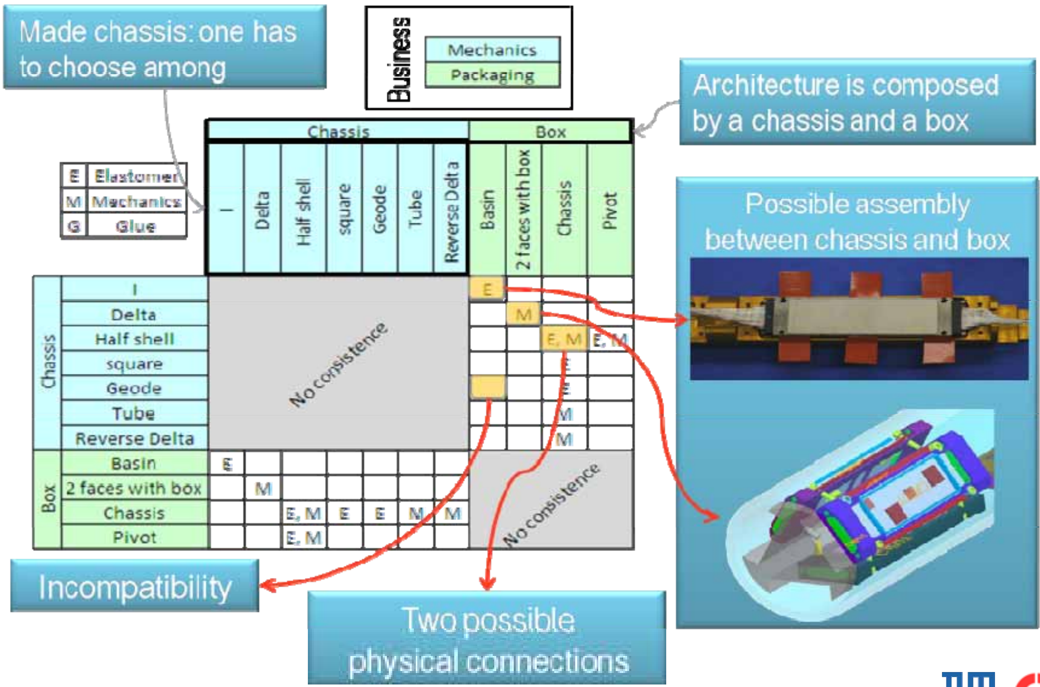


AID method: DSM with an enrich semantic

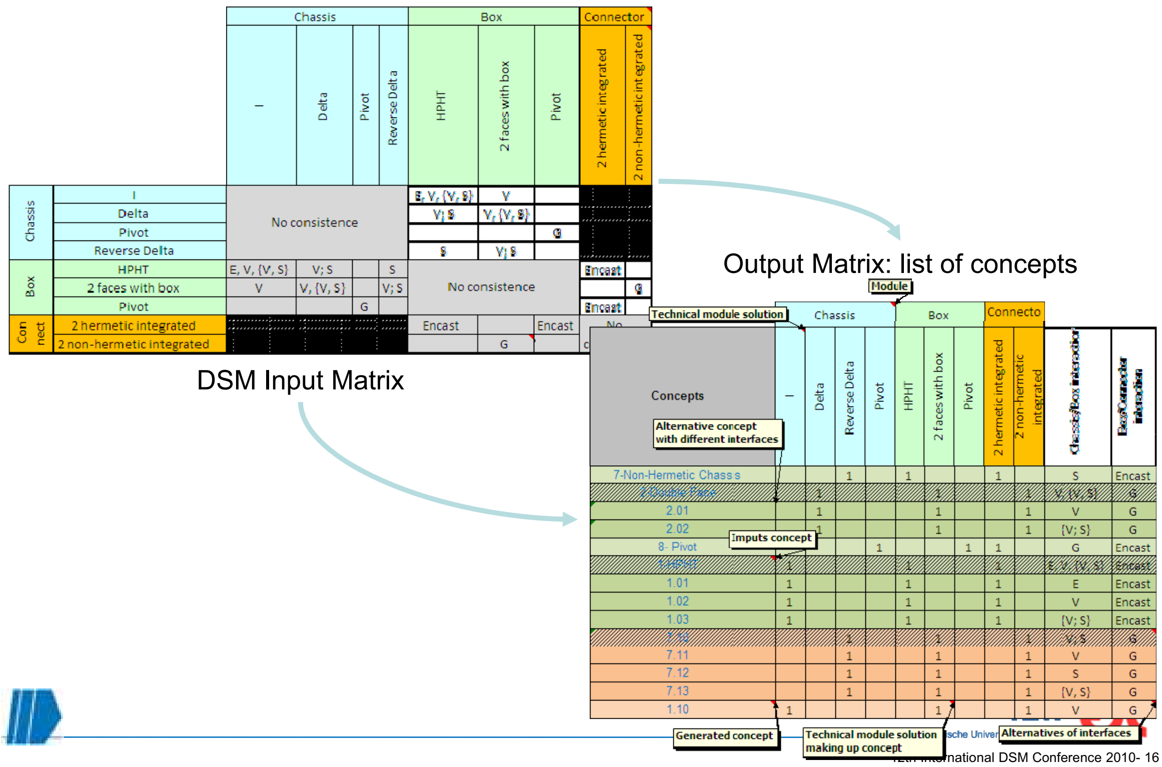
- Why expand the semantic of physical connections?
  - To have a better description of product architecture alternative with detailed physical interfaces,
  - To bring interface design information and influence from a data model soon in the generation of concepts.

- Why it's possible?
  - The space of physical connection alternative if a finite space:
    - In industry, physical assembly need to be qualify,
    - Due to high constraint, only few physical connections are available.

DSM Matrix: A MCM example



AID method: Summary of experimentations



Conclusion and further work

- Conclusion
  - Use an enrich semantic in DSM Matrix to create new design alternatives
  - Add métier area to DSM
    - Able to identify collaborative interfaces

- Further work
  - To finish the establishment of the semantic,
  - To finish the connection between physical connection and data model.