USING THE PC-DSM MATRIX TO MAP INTERACTION INTO THE INITIAL SET OF CONCEPTS

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ABSTRACT

In the context of new product development, highly constraint multi-disciplinary systems are difficult to design and generally lead to a non optimal but acceptable solution (Seepersad et al., 2008). The design of such product implies to collaborate soon in the choice of concepts. Our industrial analysis shows that concept choice is leading to collaborative problems when a design department implies a stronger influence than others. This attitude to favor one design department decreases product performance interest. As concept evaluation is a key point in product designs, this design stage must take into account design department's point-of-views. This article describes our PC-DSM matrix, based on enrich semantic in DSM, for the integration of such multi-physic interfaces early in the choice of concepts.

Keywords: Multi-physics, collaborative design, DSM

1 INTRODUCTION

In this article, we propose to semantically enrich conventional representation model of product complexity. We use a Design Structure Matrix (DSM) to represent admissible architecture connections and dependency configurations. A first contribution is the enrichment of this representation. We enrich DSM representation by a physical connection typology, allowing a range of choices at an early design stage. For a given connection, information regarding the nature of likely difficulties is incorporated into a data model; this ontological enrichment of design data makes it easier to envision and manage design challenges for multi-physics systems. This article goes further into Holley et al.'s (2010) publication.

2 PROBLEM STATEMENT

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 multi-physics 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 multi-physic 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. [Hellenbrand, 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. [Wyatt, 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 MPDS 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 MPDS method (Multi-Physics Design Scorecards) matrix based method that is organized in the three steps describes in Figure 1.

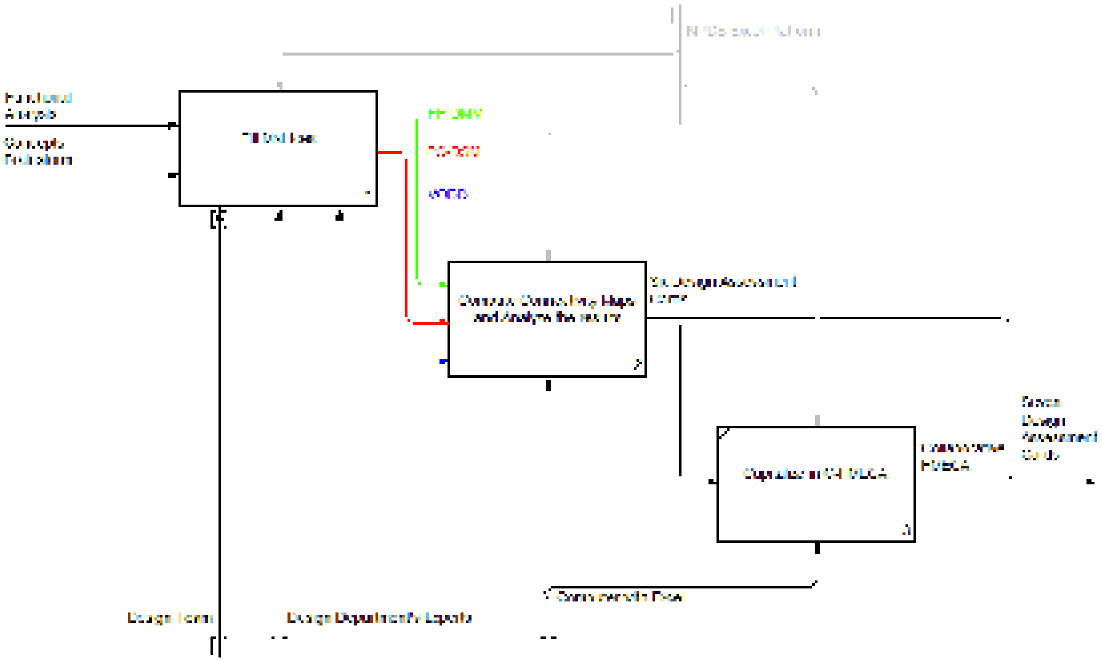

Figure 1. A1 SADT of the MPDS method

The "fill matrices" step objective is to gather project data based on "functional analysis" and "concepts brainstorming" into three matrices: Functional Flow – Domain Mapping Matrix (FF-DMM), Physical Connection – Design Structure Matrix (PC-DSM), and Voice of Design Department (VoDD), which will be used to generate six design assessment cards based on connectivity maps. The capitalization of MPDS results in the Collaborative-FMEA has for objective to quickly highly collaborative design risk about the project. Therefore, the six design assessment cards extracted from connectivity maps are used as an input.

This article will focus on the analysis of multi-physic interfaces through the use of DSM. The proposed enrich semantic will enable connections to the data model. Thus, our research aims to generate enrich concepts defining the initial set (concepts generation is explained in Holley et al., 2010, and not further explained in this article) and to improve knowledge in the design dependencies through the model of designer collaboration with other design departments early in the choice of concept. The final matrix is called PC-DSM (Physical Connection-DSM).

5 PC-DSM'S ONTOLOGY

PC-DSM is a matrix summarizing possible physical connections in different concepts based on their typology. The data gathering is based upon "rule-based formalism". The matrix is linked to the data model for physical connections. This data model contains expert knowledge concerning different design parameters influencing the architecture and their correlation. The data involved are the following:

Design Department represents the department in charge of the design of a module of the system. The design department is identified by its name and its knowledge.

Module designates a part of the system that must exist in order to perform a function. Each module has a name.

Physical Connection describes assembly between technical solutions that have the possibility of being physically assembled. It has a name and a type and is associated with knowledge, a data model, and the person who designs it.

Technical Solution represents a solution to the design of a module. It has a name.

6 PC-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 product architect or system engineer must fill in the PC-DSM matrix during the concepts brainstorming session done with the design team. We propose the following process in order to populate the PC-DSM matrix (see Figure 2) (an example, extracted from Holley et al., 2010, is given in Figure 3):

0. Module and technical solution names imported from the FF-DMM matrix are automatically filled in by the MPDS platform (see "0").
1. Fill in physical connections describing the brainstormed concepts as well as all physical connections possible between two or more independent technical solutions not part of the brainstormed concepts (see "1").

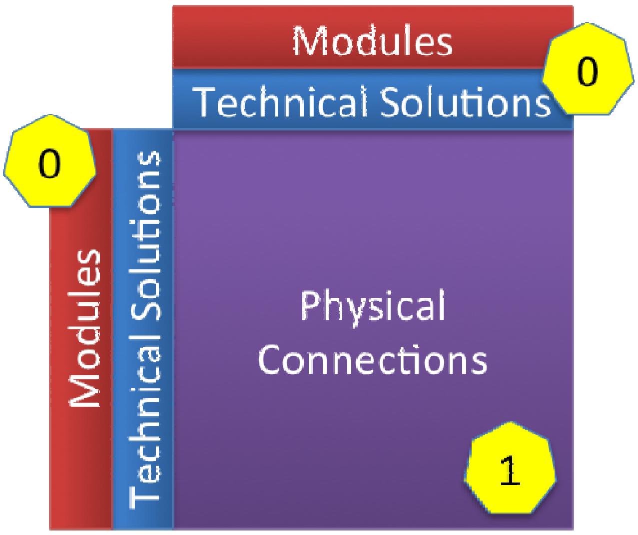

Figure 2. PC-DSM formalism

Both rows and columns ("0" in *Figure 2*) list modules and their technical solutions (concept breakdowns as well as other possible alternatives). The PC-DSM matrix is symmetric. Data concerning physical connections represent the body of the PC-DSM matrix ("1" in *Figure 2*). The rule-based formalism used to describe connections and alternatives is as follows:

An alternate way (OR) to assemble two technical solutions is described by letters separated by a comma: “XX, YY”.

An association (AND) of two physical connection types in one physical connection is described by letters separated by a comma, all enclosed in brackets: “ XX, YY ”.

Both alternate and associative types of assembly are described by letters separated by a semicolon: “XX; YY”.

		Chassis				Box			Connectors	
		I	Delta	Pivot	Reverse Delta	HPHT	2 faces with box	Pivot	2 hermetic integrated	2 non-hermetic integrated
Chassis	I	Not applicable				E, V, {V, S}	V		No assembly	
	Delta					V; S	V, {V, S}			
	Pivot							G		
	Reverse Delta					S	V; S			
Box	HPHT	Symetrical Matrix				Not applicable			F	
	2 faces with box									G
	Pivot								F	
Conn	2 hermetic integrated	No assembly				Symetrical Matrix			Not applicable	
	2 non-hermetic integrated									

Figure 3. On board electronic card case study PC-DSM matrix

The presented on board electronic card case study is a regulator board composed of a chassis, a box and a connector (called modules). Each of these modules can be achieved by the design of technical solutions as for instance, “I”, “Delta”, “Pivot” or “Reverse Delta” for the chassis module (see Figure 3).

Cells that read “Not applicable” in the Figure 3 stress that it is not possible to assemble two technical solutions of the same module. “No assembly” cells indicate modules that are not physically connected.

Letters given in the matrix characterize physical connections:

- “E” means an elastomeric physical connection between the two technical solutions: in this case, the “I” chassis and “HPHT” box,
- “V” represents physical connection by screws,
- “S” corresponds to silicon,
- “G” corresponds to glue,
- “F” represents fitting.

Thus, the cell entry that is the intersection of “I” chassis with “HPHT” box, filled in with “E, V, V, S ”, describes the three possible types of physical connections between these technical solutions. The “E” corresponds to an elastomeric physical connection, the “V” to a physical connection by screws, and the “ V, S ” to the combination of screw and silicon physical connections.

The enrichment of DSM by letters instead of a simple “X” has two mains advantages, first, it permit to create richer concepts using a classical consistent algorithm and, second, it permit to link concepts and their physical connections to a collaborative design risks analysis so called C-FMEA. The C-FMEA contains design feedback for the design of a physical connection on previous system. The objective of this Collaborative risk analysis is to bring early in the design potential design risk in order to manage design tasks.

Rows and columns can easily be added to the PC-DSM matrix in order to follow detailed low-level technical solutions. The PC-DSM matrix remains clear and as simple as possible to understand by hiding columns in function of the convergence of the initial set of ideas.

6 CONCLUSION

This paper presents our defined Physical Connection-DSM (PC-DSM) matrix based on ontology, process for their filling by product engineer or system architect and taxonomy for their completion. Ontology and taxonomy represent our principal contribution of the literature review about Design Structure Matrix. Our aim by introducing Physical Connection into DSM so called PC-DSM concerns the ability to generate more detailed consistent concepts and to bring design feedback from previous project.

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INVEST ON VISUALIZATION

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INVEST ON VISUALIZATION

Oil Market

- Extreme conditions
  - High pressures
  - High temperatures
  - High shock and vibration
- Naturally constrained
  - Mud, oil, gas and acid
  - Within a small diameter (typically 5 to 15 cm)

- Schlumberger projects
  - 5 designers
  - 7 to 15 years projects
  - 5 to 10 million $/year
- Issues
  - Duration lengthened about 40% to 150%
  - Cost may be x2
  - Reliability need 2 to 3 years of re-engineering

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Audit and Diagnosis of Design Project Management

Action Research Approach

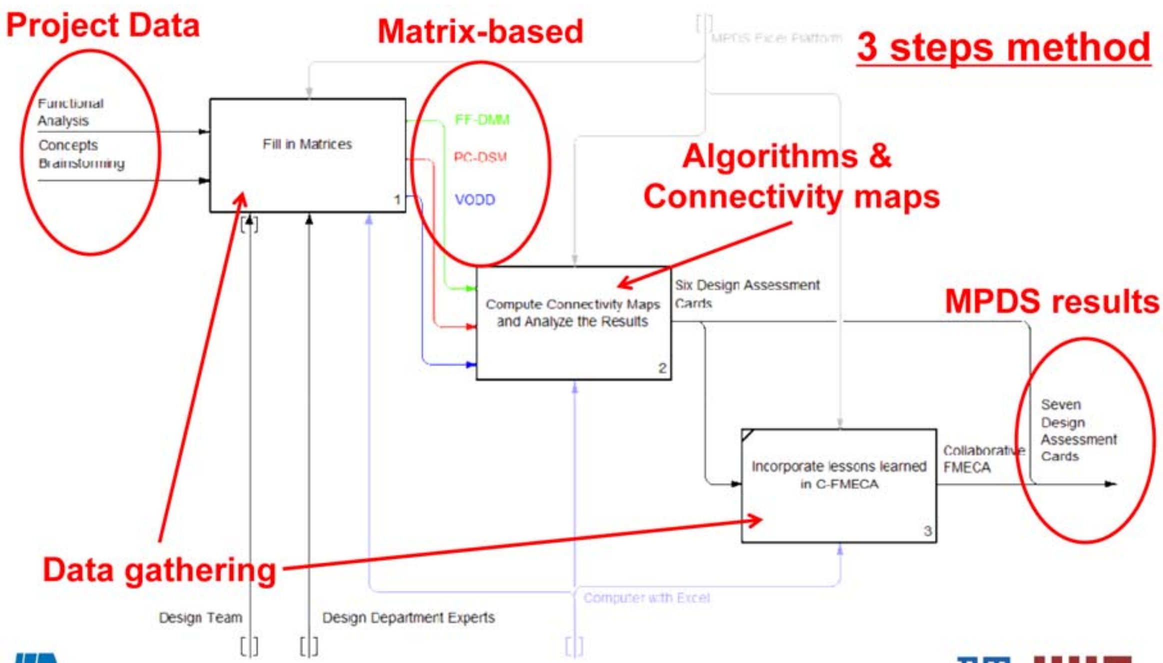
- Audit concerns about 14 projects and 25 jobs
  - Model design tasks including job interactions

- Our diagnosis
  - Design process very loosely: Extreme variability
  - No prescribed design tools: No FMECA
  - No collaborative platform: No multi-disciplinary management
  - Engineers are experts in their area of expertise

- **This article takes part of a Ph.D. work look for the improvement of design process by a simple user-friendly method to manage design collaboration: highlight highly constrained architectural zones**

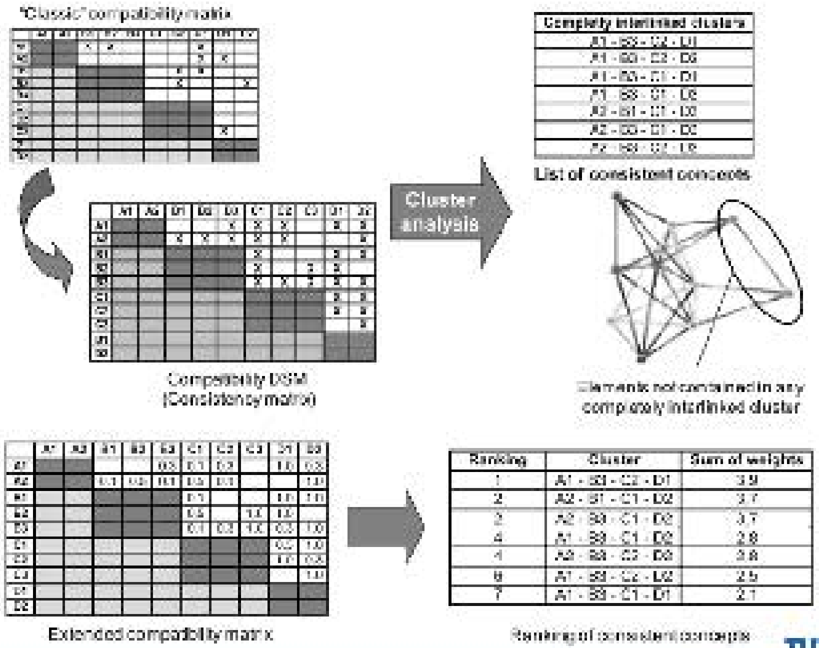
Schlumberger CENTRALE PARIS

Our Global Approach: Multi-Physics Design Scorecards Method



Literature Review: Compatibility Matrix

Hellenbrand, Lindemann,
DSM, 2008



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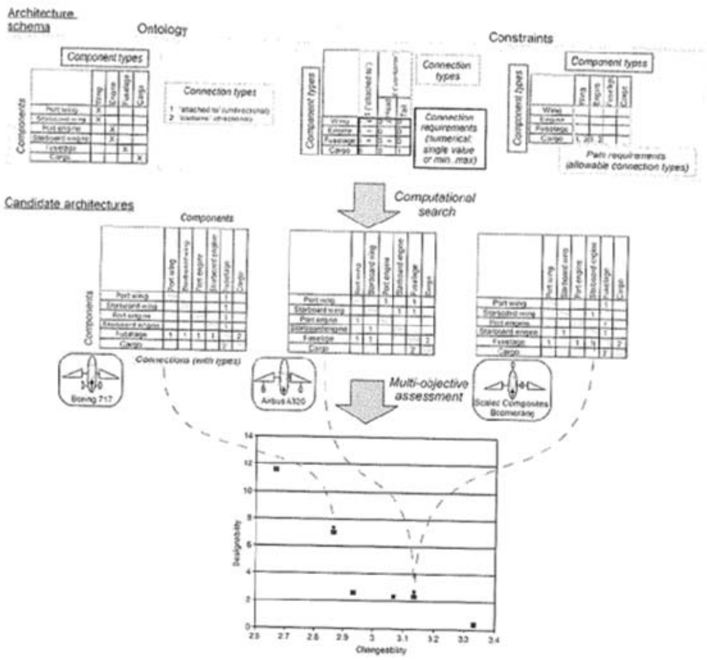
Literature Review: Inconsistency

Wyatt, Wynn, Clarkson,
DSM, 2008



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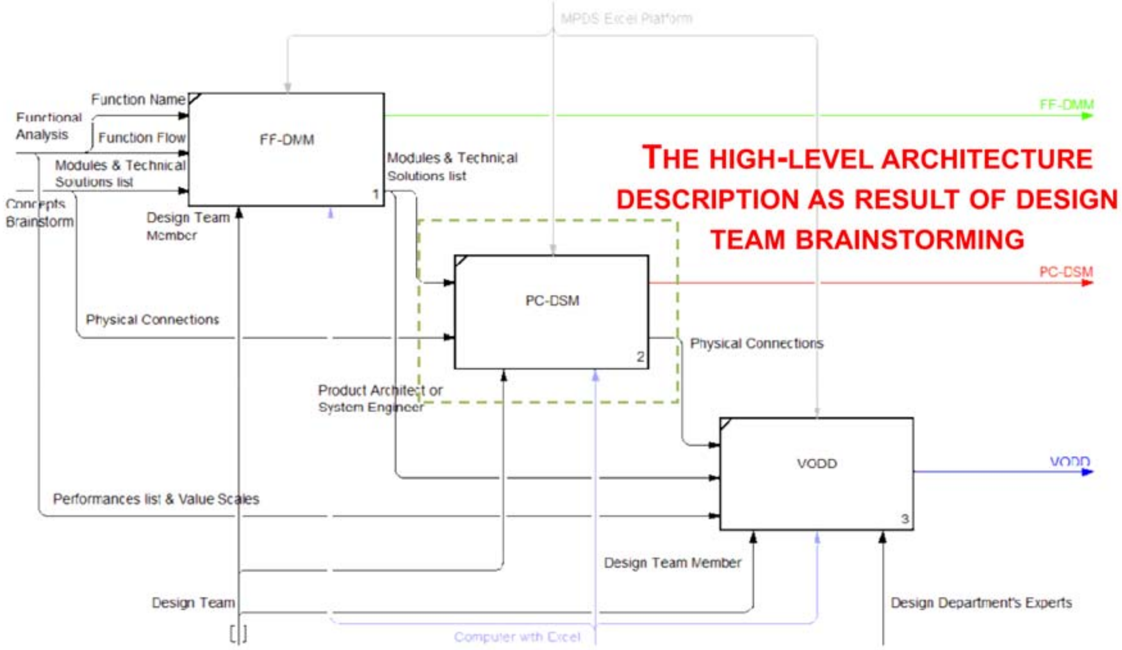
Analysis of Multi-Physics Concepts: Data Gathering



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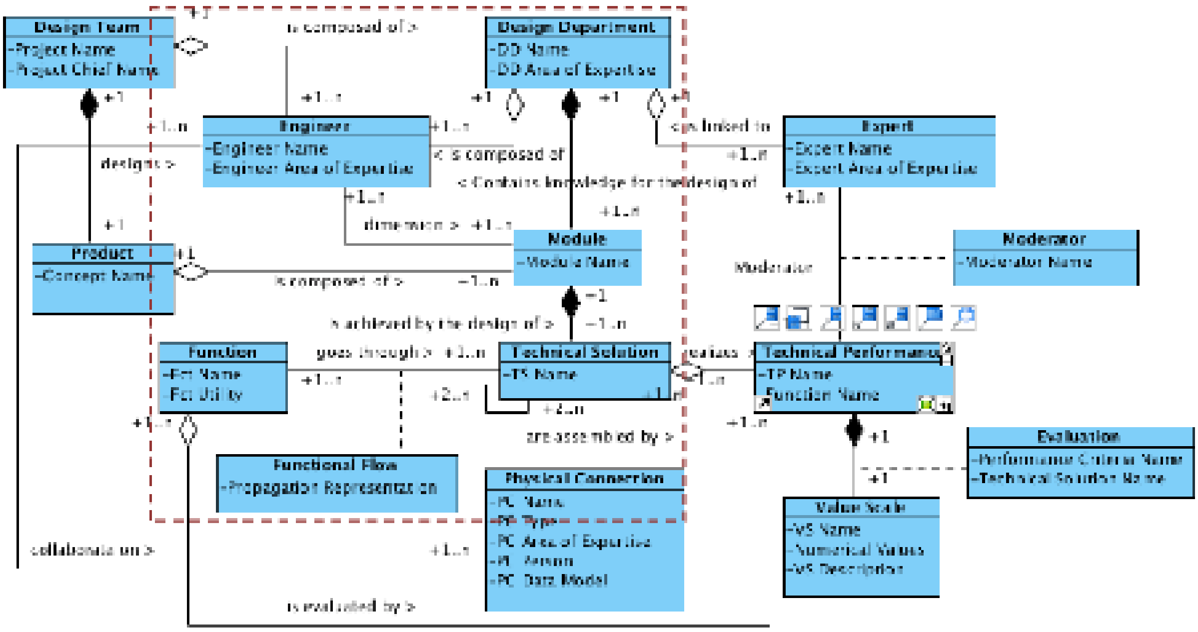
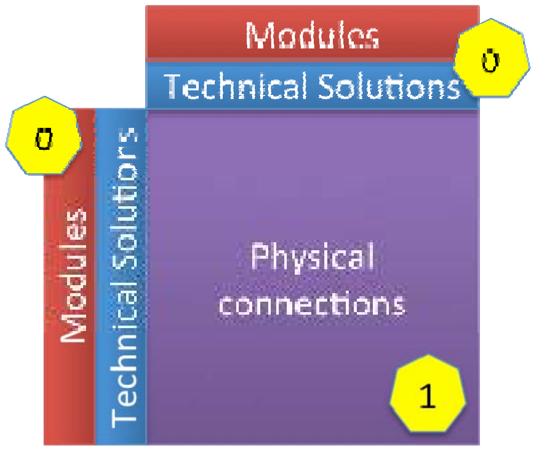
Data Gathering Ontology



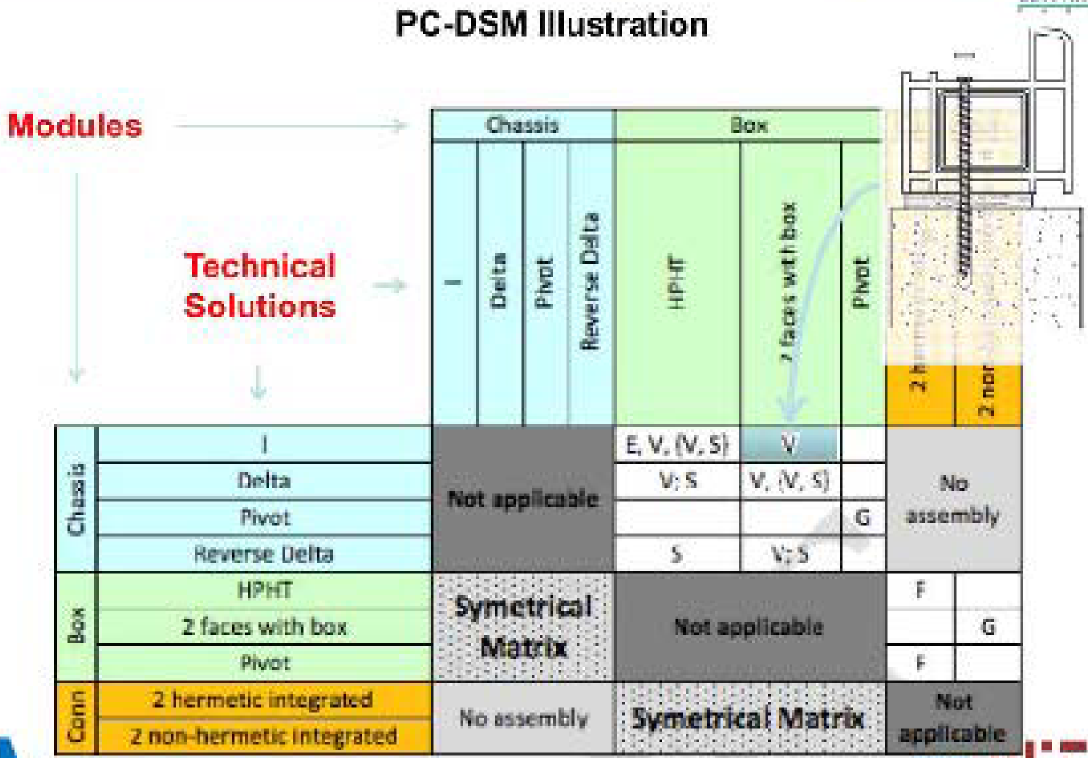
PC-DSM Protocol

- The process to populate the PC-DSM matrix:

0. Module and technical solution names imported from the FF-DMM matrix
1. Fill in physical connections describing the concepts



PC-DSM Illustration



Conclusion

- Defined Physical Connection-DSM (PC-DSM)
  - Ontology,
  - Filling process,
  - Taxonomy.

- Contribution of the literature review
  - Ontology,
  - Taxonomy.

- PC-DSM abilities
  - To generate more detailed consistent concepts,
  - To bring design feedback from previous project.