USING THE FF-DMM MATRIX TO REPRESENT FUNCTIONAL FLOW IN PRODUCT ARCHITECTURE

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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 describe our approach, based on enrich representation of functional flow in DMM, for the mapping of collaboration contribution to functions.

Keywords: Multi-physics, collaborative design, DMM

1 INTRODUCTION

In this article, we propose to semantically enrich conventional representation model of product complexity. We use a Domain Mapping Matrix (DMM) to link functions and product architecture. A first contribution is the enrichment of this representation. We enrich DMM representations with functional flow sequencing along the architectural modules; 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 developments of onboard electronic cards are an example of this multi-physics problem. Electronic card has to be integrated in a box attached to a main mechanical component. The whole assembly is going in a tube (with a diameter limited by the drill). In order to develop this product the expertise of three design departments is needed (mechanical, electrical and packaging). Every department is optimizing their design to maximize functionalities; for example the compactness evaluated through the number of electronic cards by product foot length. Eighteen months after the concept choice, the project failed due to incapability to manage the impacts of the capacitor size. Capacitor size is a key design parameter influencing the number of electronic cards by product foot length and so the function compactness.

Current approach doesn't include the identification of collaboration contribution to function achievement. The actual proposition does not permit to explore the limits of the complex problem. As key design parameters between design departments influence product functions, as it happens in our industrial example, the collaboration on capacitor size was over constraint and no dimensioning set can be found to meet expected performances.

3 LITERATURE REVIEW

The research literature is mainly addressing previous issues with the usage of Design Mapping Matrix (DMM). The aim of crossing functions and product architecture is to capture design rules. For instance Gorbea et al. (2008) propose a quite interesting method using MDM (mix of DSM and DMM) to map dependencies in architectures. Rule extraction and generation in this approach is based upon components and functions analysis. The proposed MDM is composed of three matrices: a functions-functions DSM, a components DSM and a Components-functions DMM. A set of these three matrices is generated for each architecture. Basic matrix operation, as sum and subtraction, are used to compare several matrices and therefore extract rules for each of them. Sum of MDMs enables the determination of which component is compatible with all architectures. Subtraction MDMs called “delta MDMs” is useful in comparing differences amongst two architectures. Danilovic et al. (2007) propose another approach called “Periodic Table”, mixing Design Structure Matrix and Domain Mapping Matrix, in which a DMM is used to map correlation between components and functions. This information available to characterize these data describes only the existence or not.

The main lack of the literature is that concept analysis is not related to functional analysis. Gorbea et al. (2008) propose a simple analysis of functional path in which we cannot see/identify the degree of participation of a component to the overall product performances. Moreover, the evaluation of the design concepts is proposed embracing only one global performance. Therefore this does not permit the integration of different advantages or disadvantages in possible design solutions. Moreover, this literature review is not managing that architecture can have different structure, or that functional path can be achieved in different manners.

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.

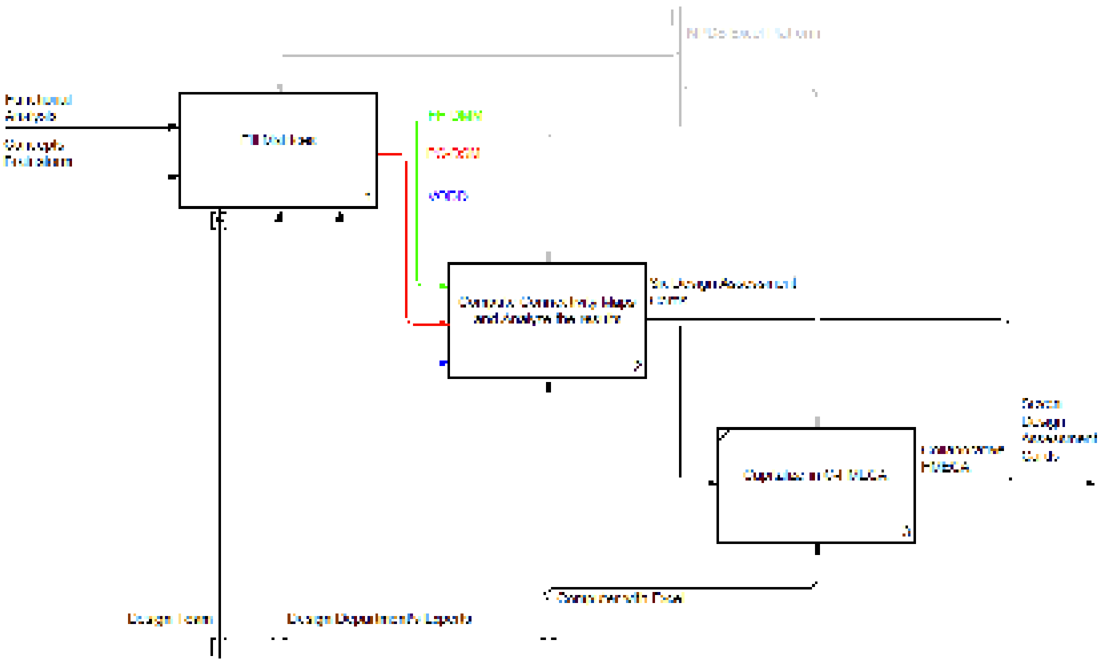

Figure 1. A1 SADT of the MPDS method

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 mapping the connections between components and functions; and the identification of collaboration contribution to functions through the use of DMM. The proposed functional flow aims at identify collaborations between design departments to functions, the obtain matrix is called FF-DMM (Functional Flow – DMM). Thus, our research wants to improve the definition of the collaboration objectives through the model of functional path in concepts.

5 FF-DMM'S ONTOLOGY

FF-DMM is a cross functional flow and architecture mapping matrix using a DMM format that is enriched by the integration of a functional flow. The data employed in the use of the FF-DMM matrix is define as 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 that of its engineers.

Function defines both what the product must do to meet client requirements (main functions) and what it must do to stay in working condition (service functions). Functions are characterized by a name and a utility. The utility corresponds to the goal of the function (whatever the client needs or the function needs to keep the system in working condition).

Functional Flow represents functional flows through the architecture of the product. Function chains are sensitive to the order of deployment of functions from one module to another module.

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

Technical Solution represents a potential solution to the design of a module. Each technical solution is assigned a name.

6 FF-DMM: AN EXPERIMENTAL EXAMPLE

This approach has been experimented on an industrial application who aims to develop onboard electronic cards under the scope of a project. The previous card developments were not able to achieve environmental constrains: high pressure, high temperature under shock and vibrations as required for our sub-project.

Any team member can construct the FF-DMM matrix after the functional analysis and concepts brainstorming. The main results of the functional analysis are functions defined with names and functional flows. The principal results of the concepts brainstorming are concepts defined with modules and technical solutions. The data collection process for the FF-DMM matrix, represented in Figure 2, is as follows (an example, extracted from Holley et al., 2010, is given in Figure 3):

1. Add function names to the matrix ("1" in Figure 2).
2. List technical solutions (e.g., "I", "Delta", "Pivot") below their modules (e.g., "chassis") ("2").
3. Assign a color to design departments, and use it to shade in the name of the module they design (in Figure 3, each design department is assigned a color).
4. Fill in the body of the matrix ("3") with the results of the functional analysis (rules for filling in the body of the matrix are explained after Figure 3).

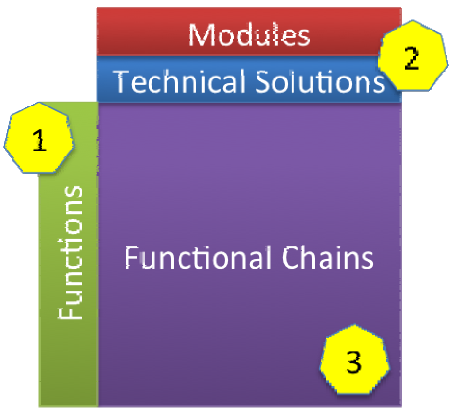

Figure 2. FF-DMM formalism

Functions are expressed in rows ("1" in Figure 2); modules and their technical solutions are expressed in columns ("2"). The data contained in the matrix ("3") presents the correlation between the potential contribution of the technical solution, which represents the architecture, to the effectiveness of the function. Functional flows are described by horizontally filling in boxes with a number. The number designates the order of deployment of the function through each of the technical solutions. The rule-based formalism used to describe function flow is as follows:

Each row located in "1" (see Figure 2) represents a function,

Parallel rows in "3" (see Figure 2) behind a function corresponds to function flow alternatives.

Function propagation through the product architecture, so called function flow, is described using number from 1 to n (an example is given after Figure 3).

	Chassis				Box			Connectors		Collar	Substrate	Electronics	Wiring
	–	Delta	Pivot	Reverse Delta	HPHT	2 faces with box	Pivot	2 hermetic integrated	2 non-hermetic integrated	Basic			
Generate power								3	3		2	1	4
Withstand pressure										1			
					1	1	1	1					
Dissipate Heat	4	4	4	4	3	3	3			5	2	1	
	3	3	3	3	2	2	2			4			
Resist shock (X)								3	3	1		5	2
	2	2	2	2	3	3	3				4		

Figure 3. On board electronic card case study FF-DMM

As an example for Power Electronic Controller Case Study, we present an example of four functions (Figure 3):

"Generate power" is a function going from electronics (indicted by a numeral "1" in the first row of Figure 3), where power is regulated, to substrate ("2"), then to connectors ("3"), and then to wiring ("4"), where motor control is connected; there are no other possibilities to achieve this function even in the case of the other concepts.

The constraint function "withstand pressure" can have two alternative paths depending on the concepts selected: pressure can be applied on the box and on the connectors or on the collar. Functional flow alternatives are represented in parallel rows: pressure applied to the collar is noted with a single numeral "1" in the corresponding module, and pressure applied to the box and connectors is indicated, in another row, with the numeral "1" in both the box and connectors modules (the "2 non-hermetic integrated" connectors field is unmarked because they cannot withstand/endure pressure).

Experiments carried out by engineers showed that shocks have two different propagation pathways within the PEC case study. Therefore, the function "resist shock" has two different functional flows. In both cases, shocks propagate from the collar (indicated in a merged field by a numeral "1" in the final two rows of Figure 3) to electronics ("5"). Based on internal function analysis, shocks can either propagate through the chassis ("2"), box ("3"), and substrate ("4") or, as indicated in another matrix row, through wiring ("2") and connectors ("3").

"Dissipate heat" is the most complex function to represent with a FF-DMM matrix, because it has aspects of both a parallel and an alternative function, depending on the concept selected. In any case, this function starts from electronics (indicated in a merged field by a numeral "1" in Figure 3). Then it can be propagated in parallel through the box ("2") and the chassis ("3"), where it can either be evacuated or it can go into the collar ("4") before it is dissipated. Or the function can be propagated through the substrate ("2"), box ("3"), and chassis ("4"), where it can either be evacuated or it can go into collar ("5") before it is dissipated.

Aside from capturing data from experts regarding the different concepts, the FF-DMM matrix also aims to validate the capacity of different brainstormed concepts to satisfy the functions requested by the client. For example, a concept composed of a "Pivot" type box and "2 non-hermetic integrated" connectors cannot achieve the function “endure/withstand pressure” when mud enters through the collar (the second row of the function “endure/withstand pressure” in Figure 4).

	Chassis				Box			Connectors		Collar	Substrate	Electronics	Wiring
	–	Delta	Pivot	Reverse Delta	HPHT	2 faces with box	Pivot	2 hermetic integrated	2 non-hermetic integrated	Basic			
Generate power								3	3		2	1	4
Withstand pressure										1			
					1	1	1	1					
Dissipate Heat	4	4	4	4	3	3	3			5	2	1	
	3	3	3	3	2	2	2			4			
Resist shock (X)								3	3	1		5	2
	2	2	2	2	3	3	3				4		

Figure 4. Functional ability of initial set of concepts presented in the FF-DMM matrix

Rows and columns can easily be added to the FF-DMM in order to track project progress and change. In order for the FF-DMM to remain clear and as simple as possible to understand, columns are hidden according to the convergence of the initial set of concepts. A part of the matrix can be extracted by a given design department, for more precise analysis of its own objectives, and then brought back to the original FF-DMM with more details.

6 CONCLUSIONS

This paper presents our defined Functional Flow – Domain Mapping Matrix (FF-DMM) matrix based on ontology, process for their filling by design team member and taxonomy for their completion. Ontology and taxonomy represent our principal contribution of the literature review about Domain Mapping Matrix. Our aim by introducing Functional Flow into DMM so called FF-DMM concerns the ability to represent function path through product architecture.

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INVEST ON VISUALIZATION

Schlumberger

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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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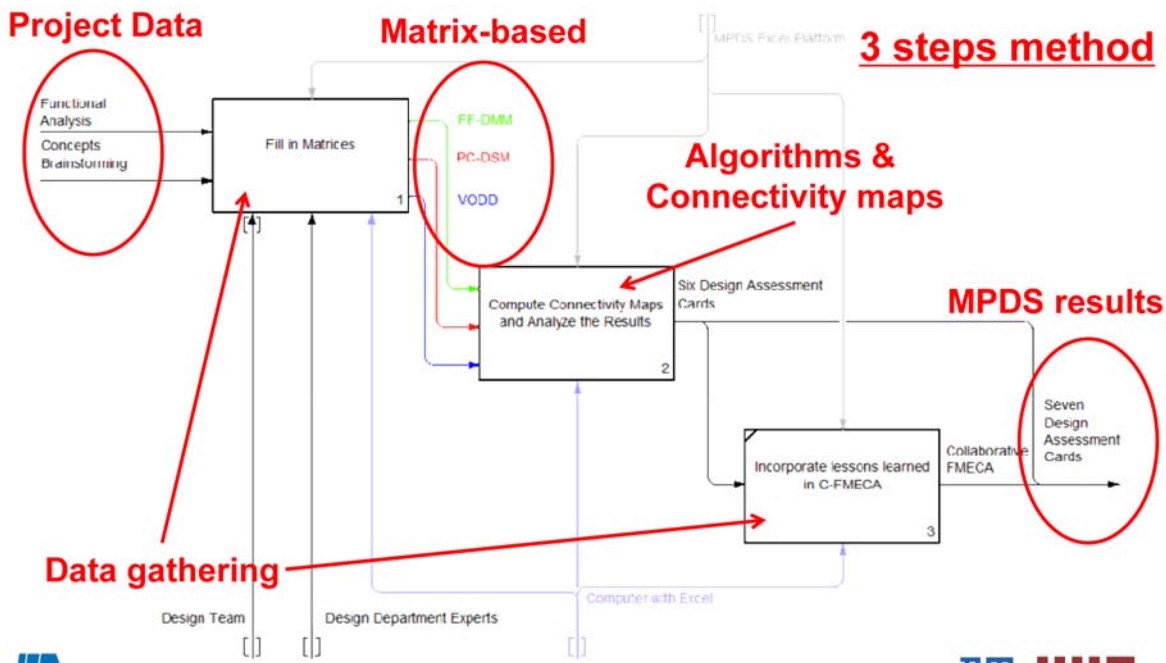
Audit and Diagnosis of Design Project Management

Action Research approach

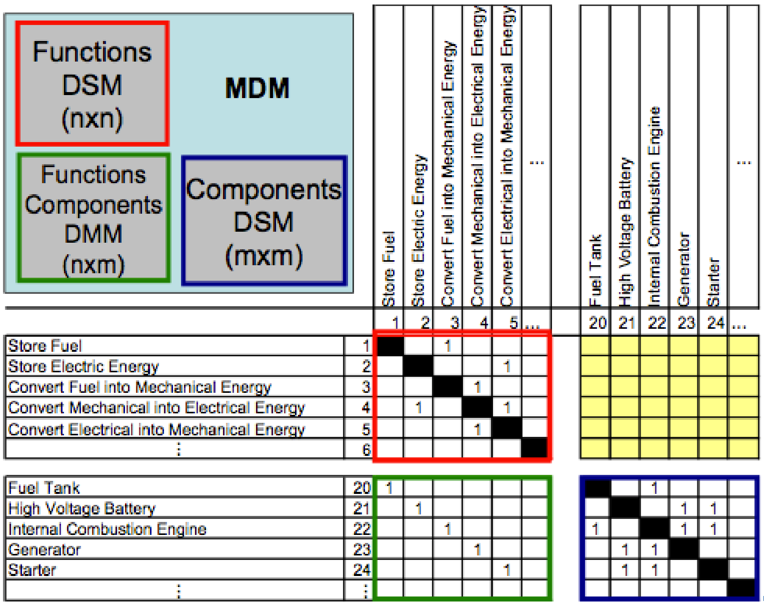
- Audit concerns about 14 projects and 25 jobs
  - Model design tasks including job interactions
- Our diagnosis
  - Design process very loosely: Extreme variability
  - No prescribed design tools: No FMECA
  - No collaborative platform: No multi-disciplinary management
  - Engineers are experts in their 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**

Our Global Approach: Multi-Physics Design Scorecards Method



Literature Review: Mapping Functions-Components

Gorbea, Spielmannleitner, Lindemann, Fricke,
DSM, 2008



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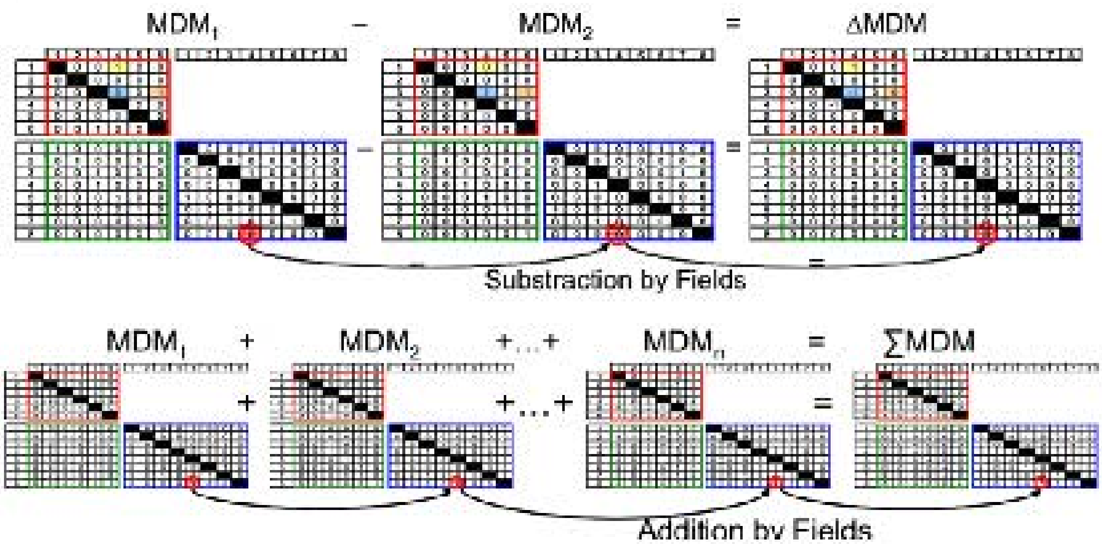
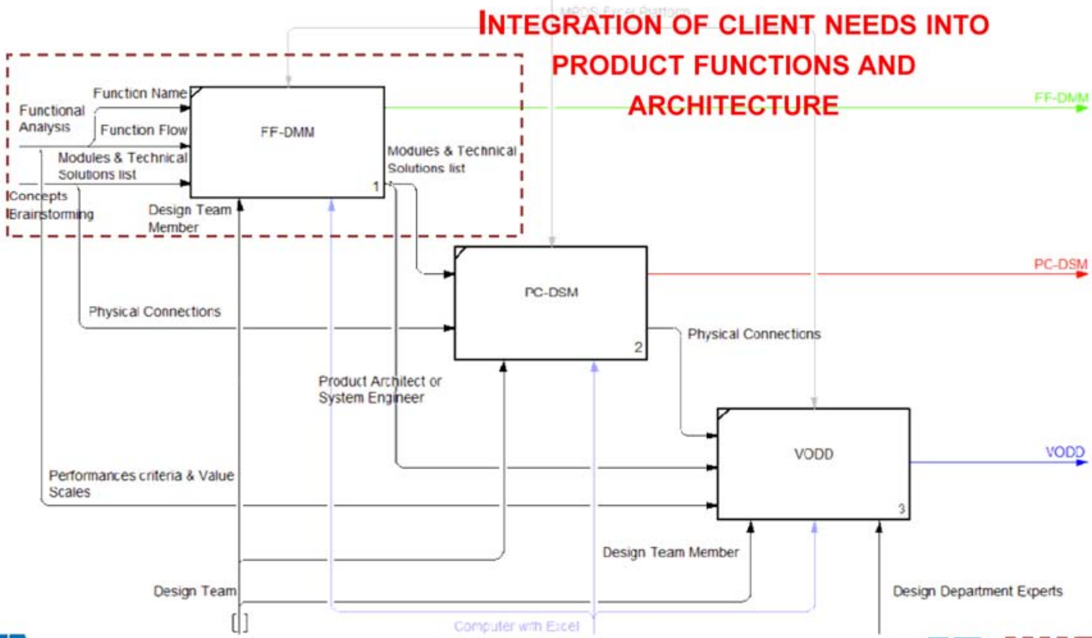
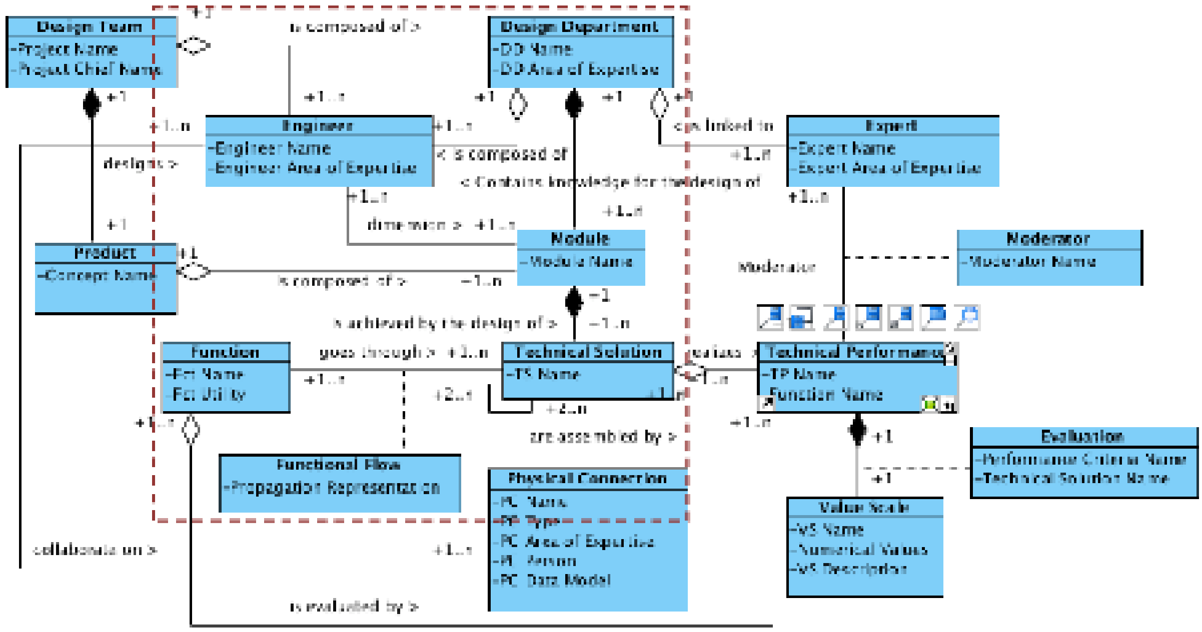


Analysis of Multi-Physics Concepts: Data Gathering



Data Gathering Ontology



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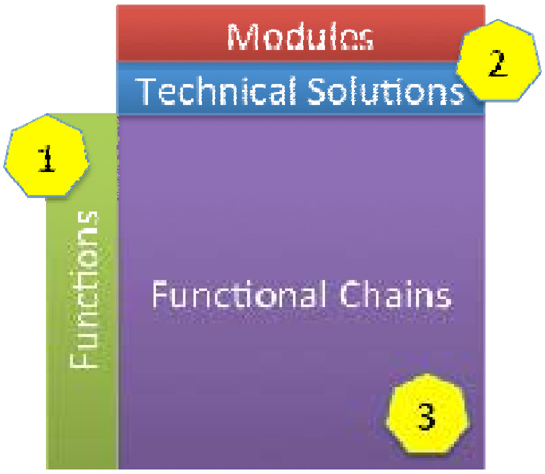
FF-DMM Protocol

- Data collection process for the FF-DMM:

1. Add function names,
2. List technical solutions below their modules and assign a color to design departments,
3. Fill in the body of the matrix with the Functional Analysis.



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FF-DMM Illustration

Mechanics Scope of study

Packaging Scope of study

Electronics Scope of study

Modules →

Technical Solutions →

Functions ↓

Modules	Chassis				Box			Connectors		Collar	Substrate	Electronics	Wiring
Technical Solutions	–	Delta	Pivot	Reverse Delta	HPHT	2 faces with box	Pivot	2 hermetic integrated	2 non-hermetic integrated	Basic			
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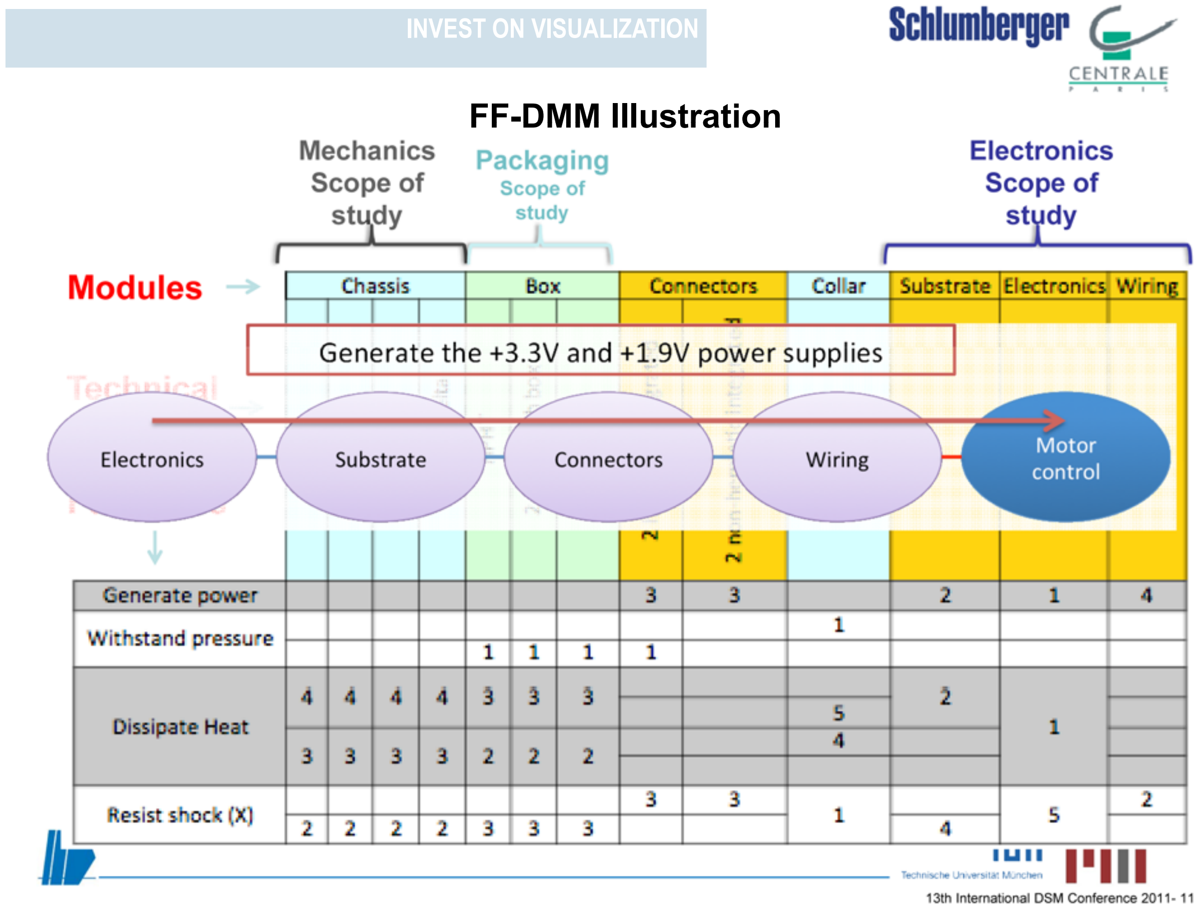
	3	3	3	3	2	2	2			4			
Resist shock (X)								3	3	1		5	2
	2	2	2	2	3	3	3				4		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CENTRALE
FF-DMM Illustration
Mechanics Scope of study
Packaging Scope of study
Electronics Scope of study
Modules
Chassis
Box
Connectors
Collar
Substrate
Electronics
Wiring
Generate the +3.3V and +1.9V power supplies
Electronics
Substrate
Connectors
Wiring
Motor control
Generate power
Withstand pressure
Dissipate Heat
Resist shock (X)
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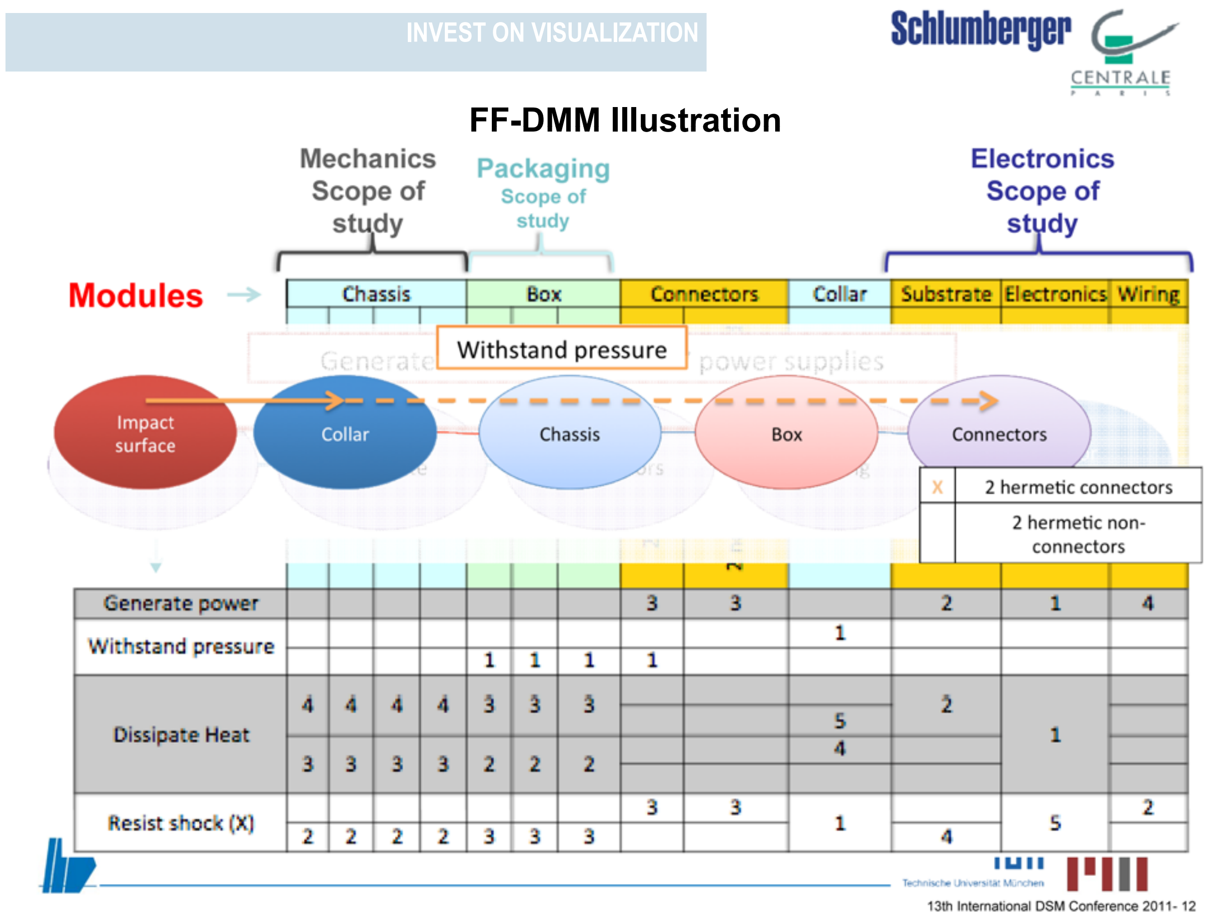
INVEST ON VISUALIZATION
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CENTRALE
FF-DMM Illustration
Mechanics Scope of study
Packaging Scope of study
Electronics Scope of study
Modules
Chassis
Box
Connectors
Collar
Substrate
Electronics
Wiring
Withstand pressure
Impact surface
Collar
Chassis
Box
Connectors
X
2 hermetic connectors
2 hermetic non-connectors
Generate power
Withstand pressure
Dissipate Heat
Resist shock (X)
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Conclusion

- Defined Functional Flow – Domain Mapping Matrix (FF-DMM)
  - Ontology,
  - Filling process,
  - Taxonomy.
- Contribution of the literature review
  - Ontology,
  - Taxonomy.
- FF-DMM ability
  - To represent function path through product architecture.