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ON THE USE OF DESIGN THEORIES TO SUPPORT INNOVATION AND ORGANIZATIONAL PROCESSES

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1. Introduction

With the growth of interest in design phenomena since the mid 50s' there has been consistent efforts to produce adequate formal theories capturing universal aspects of design processes. Starting with early theories adapted from artificial intelligence (such as Simon's Problem solving), a number of formal design theories such as the General Design Theory of [Yoshikawa 1981] or Axiomatic Design of [Suh 1991] have been suggested. Efforts in the last decade such as C-K design theory [Hatchuel and Weil 2003] or Infused Design [Shai and Reich 2003] have fuelled academic debates on the possibility and utility of general formal design theories.

While theoretical efforts continue, doubts and criticism has been raised within the community regarding the accuracy and the utility of these formal approaches. Some authors such as Buxton do not believe in any such utility, or to the necessity for such an endeavour: "(…) it is not my intention to present you with a deep treatise on some idealized design process. Frankly, I would doubt the value of such a thing, even if I thought one could be written" [Buxton 2007]. Others have argued that empirical evidence demonstrates that designers do not act following the rationale of these theories [Cross et al. 1992].

In the 1980s, several research programs carried out empirical studies on designers, often in partnership with specialists in cognitive psychology. The aim of these programs (in particular the one made by Pahl, Ehrlenspiel and Dörner and financed by the German research organization DFG) was to "observe and describe the design processes with the methods and concepts used in cognitive psychology and empirical psychology, with a view to deducing *the foundations of a descriptive theory of design processes*" (Ehrlenspiel and Dörner, quoted by Matthias Heymann, p. 460). In practice, these studies did not have an impact on design theories, as confirmed by Matthias Heymann: "They provided a great deal of knowledge concerning the complexity of design processes; this knowledge tended to stress the difficulties involved in establishing a general theory of design rather than favour such a theory" (p. 477).

The objective of this paper is to contribute to this debate. In the introduction of their paper, [Braha and Reich 2003] argue that building formal theories can serve two purposes. First, it will allow us to better understand our limits of formalizing design and the limits of automating it. Second, studying mathematical models of design could produce practical guidelines or ideas for improving design support and practice. Accepting these premises, we would like to go one step further: we argue that *design theories allow generating design models* specifically helpful in supporting the management of organizational and innovation processes.

Assuming there is no one best model and that design activities can be organized in various ways, it becomes interesting to discuss the interaction of models and their utility as instruments in diagnosing and supporting the organization of design activities. Although engineering practice and education make heavy use of models, rarely (if at all) in Engineering Design literature the role and impact of models to the organizational processes have been discussed in depth. In comparison, work from decision theory and operations research has extensively debated the role of modeling as a specific and valid methodological approach in management practice and research.

The current paper presents a real-life industrial case where models generated based on various design theories have been used to investigate both the organizational rationales and different design paths to increase the efficiency of the organizational process and support the innovation activities.

In the next section, we outline some major ideas related to modeling in an organizational context. Section 3 reminds some formal design theories that have been helpful with the case. Section 4 presents the industrial case in detail. And the last section concludes with a discussion of the impact of the models in the presented case and provides some general conclusions.

2. Using models as management support instruments

The use of models as management tools has a long history spanning back to the rise of Operations Research (OR) and System Science (SS) paradigms after the Second World War. These research domains, having strong applied components, generated intense debates regarding the place of the analyst and the model within organizations [Moisdon 1997]. The 'analyst' has been described as being in charge of an "intervention process", impacting the firm through the introduction of a construction - the "model" [Hatchuel and Molet 1986], [Liberatore et al. 2000].

Over the decades following the WW2, different stances have been adopted regarding the epistemological status of models in the OR/SS literature. Early analyses attempted to build foundations of modeling on a positivist epistemological ground. Models were argued to be descriptive (or realist) or prescriptive (normative). The legitimacy of the models was argued on the basis of their scientific roots and soundness. And the model was seen as the supplier of the rational and optimal solutions that should be followed by the practitioner and the organization. This positivist paradigm has seen the failure of a majority of the OR/SS models when confronted with the organizational realities [Landry et al. 1996]. The concerns of the specialists regarding the failure rates of the models motivated other approaches, which eventually came from the rise of a constructivist view of knowledge production in epistemology, gaining momentum in many other scientific fields. Modeling started to be discussed by many authors as being a constructivist activity (in the epistemological sense) of scientific knowledge production. In this perspective, modeling is intentionally constructing an entity in order to comprehend our experiences and relationship to a particular phenomenon. Modeling is a way of understanding and thus it is a process of epistemological legitimization of the knowledge produced by the investigation [Le Moigne 2003]. Thus modeling does not describe reality but only builds a new and specific point of view about this reality. Its value can be defined only by an in situ discussion of the fruitfulness of such point of view in comparison to other points of views.

In an iterative, participative intervention research context, the model is refined through researcher's interaction with the field and the confrontation of the model to organizational structure. As numerous reported intervention research cases demonstrate, the process is non-linear involving multiple iterations between the formulation of the model and the confrontation of the model to the processes observed by the researcher.

Ultimately, models aim at bringing a rational ground on which a particular organizational context can be given a new meaning and some innovative collective action might be conceived and executed. As such, the elaboration and the use of scientific models are part of 'rationalization' efforts for the management. Rational models are important means of intervention by virtue of the reactions they generate (acceptance, rejection, questioning, learning effects, organizational change etc). Thus, they can be seen as analytical tools in the hands of the researcher for the decoding of the dynamics of an organization [Hatchuel and Molet 1986], [Liberatore et al. 2000]. The model-based intervention research has thus common features with other experimental approaches as it is based on the study of organizational behavior when a particular modification is attempted through the perturbation given by the model [Hatchuel and Molet 1986], [Liberatore et al. 2000].

It is worth reflecting upon the rationality the models bring forth. [Hatchuel and Molet 1986] explain that models are "rational myths". They are rational in the sense that they are internally coherent, allow dialogic argumentation and the inferences that can be drawn are non-contradictory. They are also myths in the sense that, despite all effort from the analyst to make the model useful, accurate and relevant to a given problem setting, they are creations that reflect reality from a particular perspective. It is by virtue of these dual characteristics that models allow a fruitful intervention [Hatchuel and Molet 1986], [Liberatore et al. 2000]. This allows a multiplicity of models while maintaining their consistent, thus rational properties. This, in turn, gives to the analyst the possibility to interact with the organization at multiple levels and with all the stakeholders, integrating their opinions and preferences. This interaction of the model with the organization, the very basis of the intervention process, allows evolving both the model and the organization. Modeling is thus a double loop process involving both theorizing about the perceived problem and the organizational process.

The usefulness of models has been debated under the topics of validation and legitimacy in OR/SS literature. While in the literature there is a converging assessment that models need to be validated in order to be organizationally well received and used, there are contradictory and diverging views on how a model can be validated. There exists an abundant literature on model validation offering dozens of criteria such as accuracy, coherence, and reliability. While these criteria remains interesting, most of them often consider purely logical or scientific forms of validation. The organizational impact is neglected. Following the change in the epistemological basis of modeling, recent work has rather focused on the impact of the model to the organizational vision, contracts and practices. Under such perspective, the utility of a model depends on its capacity to influence the trajectory of the project by helping the formulation of a new vision and associated courses of collective action.

Such view fits with the innovative design activities that are largely dependent on teams and management behavior. One of the most robust findings of design research is certainly that the process of design (task, understanding, organization, quality of exchange) has an impact on the output. Thus if design models have an impact on such process, they would contribute to the design improvements in a collective way. And this is a perspective that is different from the traditional debate about design theory that discusses if (individual) designers design like predicted by the theory. A different hypothesis can thus be formulated: even if a design theory cannot capture the whole reality of design, it may offer design models that impact fruitfully the collective design process and design itself. In an innovation context where significant novelties are sought on the product, the utility of the model can thus be discussed with respect to the change in the organization that would allow this novelty. After the presentation of the case, we shall discuss the utility of the design-theoretic models based on this notion.

3. Design theory

This section recalls the basics of Axiomatic Design Theory and C-K design theory.

3.1 Axiomatic design

Axiomatic design theory has been developed by [Suh 1990] in his book "Principles of Design". Suh claims that the fact that there exist good solutions and bad solutions indicates that there are traits or attributes distinguishing good ones from bad ones. To build a formal ground that would allow expressing the universal criteria of the quality of design solutions, Suh uses a particular ontological structure. According to his work, design happens in two domains, a Functional domain, where the set of all the functional requirements (FRs) exist and a Physical domain, where all the design parameters (DPs) exist. The work of the designer is to build a mapping between these two worlds, Figure 1.

Suh gives two mathematical axioms that would allow evaluating quality of the mapping. The first axioms states that an acceptable design implies for each FR there is one and only one associated DP: for each function there is one implementing design parameter and vice versa. This axiom is often used with a matrix-based visualization, where an ideal matrix is diagonal. The second axiom postulates that the design that minimizes the quantity of information between an FR and the target FR is best. In most applications, this second axiom is rather neglected.

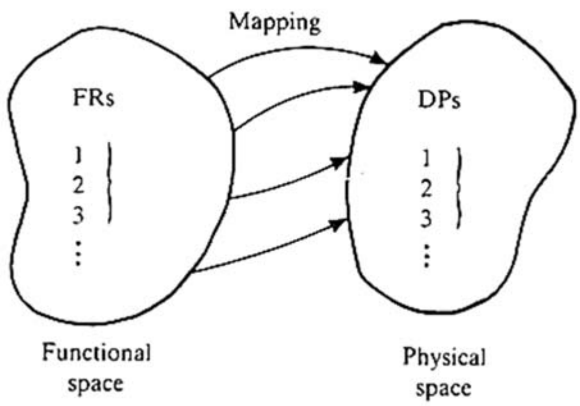


Figure 1. Design as a process of mapping [Suh 1990]

3.2 C-K design theory

C-K theory [Hatchuel and Weil 2003] describes design reasoning based on the distinction and interaction between two spaces. A knowledge space represents all the knowledge available to a designer (or to a group of designers) at a given time. These are propositions that the designer is capable of declaring as true or false; i.e., propositions whose logical status are known to the designer. A concept space represents propositions whose logical status are unknown and cannot be determined with respect to a given knowledge space. These are propositions that can be stated as neither true, nor false by the designer at the moment of their creation.

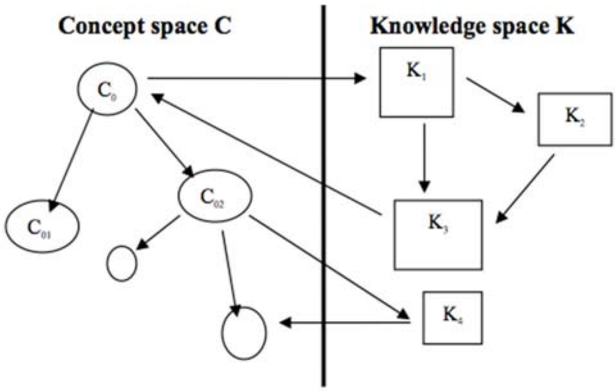


Figure 2. Concept and knowledge spaces [Hatchuel and Weil 2003]

Concepts are descriptions of an object of the form "C: there exist an object x with the properties p_1, p_2,..., p_n" such that C is *undecidable* with respect to current K. According to C-K theory, creative design begins by a conceptual expansion that forms a concept. A novel and unusual property is added to a concept to form a new concept. The elaboration of concept can then be continued either by further expansions or by restrictions (that is by adding usual properties of the initial concept, e.g. tires for life are round). Conceptual expansions or restrictions are called partitioning in C-K theory.
When elaborating a concept space, a designer might use her K space, either to partition further the concepts, or to attempt a validation of a given concept. This last type of operation is called K-validation and it corresponds to the evaluation of a design description using knowledge. The result of a K-validation is positive, if the designer acknowledges that the proposition "there exist an object x with properties $p_1,p_2,...,p_n$" is true. The result is negative, if the knowledge available to the designer allows him to state that the proposition is false. Often the validation of a concept is not readily possible. In order to validate concepts, new knowledge warranting the existence conditions of such an object should be acquired. In terms of C-K theory, knowledge should be expanded. The expansion of knowledge space is called K-expansion. The central proposition of C-K theory is thus design is the interaction and dual expansions concepts and knowledge.

4. Case study

The work presented here has been accomplished within Theory and Methods of Innovative Design Chair of Mines Paristech. The case is based on the work of students realizing their internship projects with long-standing partner companies, with the supervision and help from both the partner companies and Mines Paristech's pedagogical teams. The project that lasted 9 months is a process placed within a broader intervention and partnership context spanning over the last five years. Many types of models have been used during the project. Here, we shall focus on the use of models generated based on design theories. Numerous technical and strategic details of each case will necessarily be omitted due to confidentiality reasons as well as for easing the readability.[1]

4.1 Context of study: A green solution for the installation of oil tubes

TubeCorp is a world leader in premium tubular solutions for various industries with over 3 billion € worth annual sales, and more than 30 production sites in over 20 countries. The core competency of TubeCorp is metallurgy, they have the widest product range in their sectors with solutions including more than 200 types of steel, up to 1500 mm diameter tubes for an extremely varied range of tubular applications including tubes for construction, foraging, thermal and nuclear energy centrals, mechanical and conduction uses.

The presented case took place in Oil Country Tubular Goods branch of the firm where tubes for oil and gas extraction are designed and manufactured. Such tubes are produced with a diversity of diameters (internal and external) and steel compositions, and with a maximum length of 150m. For transport reasons the initial tubes are then cut and processed to 12m length tubes that can be reassembled based on VAM connections. One of the major concerns in such industries is to propose reliable solutions to leakage problems in junction points of the tubes, knowing that they are going to be subject to extremely hard conditions during their life cycles (internal and external pressure, corrosion, abrasion, acidic substances such as CO2 or H2S).

Figure 3. An example of a VAM connection

Traditionally, grease was being used for such connections to be stocked and screwed. These greases containing heavy metals can protect against corrosion and can provide good lubrication for screwing of the tubes. On the other hand, these materials are not environment friendly and not very easy to handle in extreme weather conditions (e.g. in extremely cold regions, the greases freeze which makes it hard to apply or remove). The company launched a project to find a coating solution that would allow replacing the grease solution. This was expected to be a straightforward project since the coating seemingly had no reason to interact with other parts of the design such as the VAM architecture or the base material. As the project advanced, this proved to be a very strong assumption and the internal project team has encountered unexpected complications.

4.2 Investigating the problem parameters

The intervention started with an analysis of the role of the grease within the context of tubular solutions design and installation. In the classical solution, the grease was implementing two functions. The first was to protect the tube against corrosion during stocking and transport. The second was to provide lubrication while tubes were screwed together.

[1] Further details can be found in Robin, J-R and Sebag, V., Design of tubes that can be installed without grease: an exploration strategy minimizing the risks (in French), 2011, Mines Paristech.

(a) (b)

Figure 4. On the left, tube stockage area, on the right, the application of grease to the tube

Two types of greases were being used for each function. For stocking purposes, a first kind of grease is applied at the manufacturing plant. The tube is then sent to the foraging wells where they are washed before the second grease is applied, this time, for lubrication. Let us note that the classical solution was being used by all employees of all clients in charge of the joining of the tubes in every corner of the planet: this was a general solution. This situation was modelled by Suh matrices in order to analyse and communicate for further validation.

With grease		FR: Functional requirements			
		Waterproof	Shock resistance	Corrosion resistance	Lubrication
DP: Design Parameters	Connection	X			
	Protective caps		X		
Coating	Grease for stocking			X	
	Grease for screwing				X

Without grease		FR: Functional requirements				
		Waterproof	Shock resistance	Corrosion resistance	Lubrication	Environment
DP: Design Parameters	Connection	X				
	Protective caps		X			
	Coating			X	X	X

Figure 5. The project's overall objectives

Considering the 1st axiom of Suh, we can immediately see that this representation is already signalling some problems. From the point of view of the TubeCorp, the grease was not an element to take into account during design; they were only using a certification process to determine which specific greases could be used given a connection type. During this process, TubeCorp learns nothing about the design of the grease. With the coating solution, the company intended to acquire more knowledge and competencies. However, such a project requires significant expertise in chemistry and the company decided to collaborate with a specialized research company, ChemCorp.

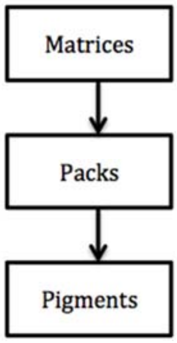
During the first few cycles of the study, it was realized that there might be additional opportunities that would help increasing the value of the products. Different regions such as Nordic sea, Russia and Middle-east have different requirements due to legislations, climate conditions or work habits such as non-toxicity, non-extrusion or resistance to very high or very low temperatures. The company was considering ways to address all these requirements at once, which changed the structure of the problem.

DP: Design Parameters	FR: Functional Requirements								
	Waterproof	Shock resistance	Corrosion resistance	Lubrication	Non-toxicity	Non-extrusion	Non-Stickiness	High T°	Low T°
Connection	X								
Protective caps		X							
Coating			X	X	X	X	X	X	X

Figure 6. Coating as an over-constrained parameter

4.3 Modelling partner's design rationale

Since the original solution was a decoupling element, the natural tendency was to substitute with a coating solution that would allow the same decoupling. As shows the figure 6, this new matrix shows that there is an over-accumulation of FRs on the coating. Since the expertise about the coating lies outside of the firm at this stage, TubeCorp could not provide new design parameters constituting the coating that could be studied to avoid the revealed dependence relationships. The intervention team, studying the design process of ChemCorp, discovered that, contrary to TubeCorp, they use several new parameters that can be used to such effect.



DP: Design Parameters	FR: Functional Requirements				
	FR1	FR2	FR3	FR4	FR5
Matrix	X	X			
Pack			X		
Pigment 1				X	
Pigment 2					X

Figure 7. Models of the design process followed by ChemCorp

ChemCorp uses a linear process of design, where they select first a chemical matrix, then the packs, and last, the pigments to be used. The matrix is selected according to two killer criteria included in the original project description. The work of the chemist is thus to find an ingenious combination of pack and then pigments that would give the requirements. After several attempts it has been realized that the performance of the matrices was dependant of the later design decisions – putting in jeopardy the expected compatibility with the killer criteria. Moreover, during the project TubeCorp has modified the degree of importance for the second criteria, but the matrix used while experimenting with the packs and the pigments has not been changed.

DP: Design Parameters	FR: Functional Requirements				
	FR1	FR2	FR3	FR4	FR5
Matrix	X	X			
Pack			X		
Pigment 1				X	
Pigment 2		X			X

Figure 8. Hidden and ignored interactions in ChemCorp's design rationale

The representation of these observations by Suh matrices gives Figures 8. It becomes possible to understand that some parameters that the lab was using were heavily coupled with one of the FRs. The second pigment was deteriorating performances on the second function. But the chemistry lab did not have a detailed model or a decomposition of these functions and parameters that would allow studying this coupling. An understanding of the underlying interactions has never been targeted. Also, after the revision of the second criteria, work has been continued only on the pigments, not tracking back to previous design decisions regarding the choice of the matrix or the pack.

4.4 Modelling the learning strategies

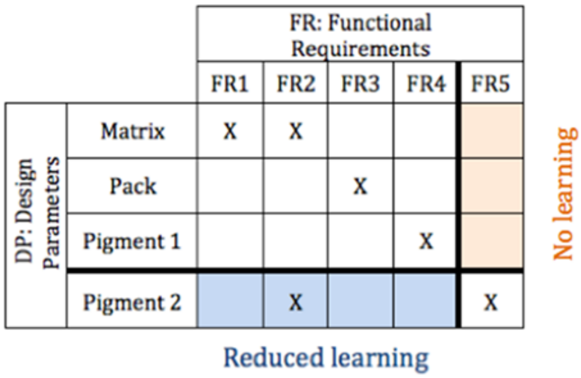


Figure 9. Models of learning rationale of ChemCorp based on Suh matrice representations

Based on this analysis the team had been able to gain better insight to the design process of ChemCorp and potential problems. In fact, to achieve the desired functionalities the interaction and interdependence of the diverse elements with the matrix should be *understood*. This requires a structured process with specific learning objectives. However, the linear process used by the lab does not allow such learning. Their process reduced the design process to an optimisation process. In the first phase the engineers creates a product formulation based on an ingenious combination. The solution is at best a local optimum. Then, they proceed to the exploration of some linear combinations of the pigments in proximity of the local optimum in order to marginally improve the formulation.
This strategy seems to be quick providing the maximum value (a general solution for all the constraints). However, from a learning standpoint, it is far from optimal (Figure 9); The chemists learn only about the result of a random change in linear combination. Since the initial choices are not revised, it is only about the last pigment (and the variation of its effects) that something is learned. Without gaining in any understanding about the interaction of various elements within the matrix. This learning strategy does not produce knowledge that would allow essential changes in strategic design options.

4.5 Impacting the innovation process: The design of a new market segmentation for better learning opportunities and probability of success

The analysis so far exposed a need to reconsider the strategic priorities of the project in order to maximise learning opportunities, especially regarding the phenomenology of the Suh matrix (the interactions of various elements). A detailed Suh matrix categorizing as exhaustively as possible the objectives that can be envisaged to address different markets, client requests and relationships (couplings) between these requirements has been constructed for various market opportunities. This matrix provided a possible product/market segmentation of corresponding a specific geographical zone, well type, connexion type, and client characteristics. The representation has served as a direct support during meetings between Marketing and R&D departments where, finally, three segments has been accepted corresponding to three major markets (Nordic Sea, Middle East and Cold countries e.g. Siberia).
This new segmentation modifies significantly strategic considerations about the project. Initially, the project aimed at designing a unique coating solution based on a combination of {M, Pa, Pi} to

implement the functions. {F1, F2, F3, F4, F5}. With the segmented product range, not all of these functions are required in every segment. The three new products that are now being targeted covers different functional groups {F1, F2, F3}, {F1, F2, F4}, {F1, F2, F5} while all of the market demands are being addressed by at least one product.

4.6 A new strategy of exploration minimising risks

To capture the impact of this new strategy, a model based on four criteria was developed. These criteria are (estimated) value of the solution, estimated cost of the solution, probability of success and level of learning. Based on these criteria, we can represent the perceived and the actual evaluation of the project, (Figures a and b). In the initial vision, the criteria concerning chances of success and the learning outcomes were not taken into account.

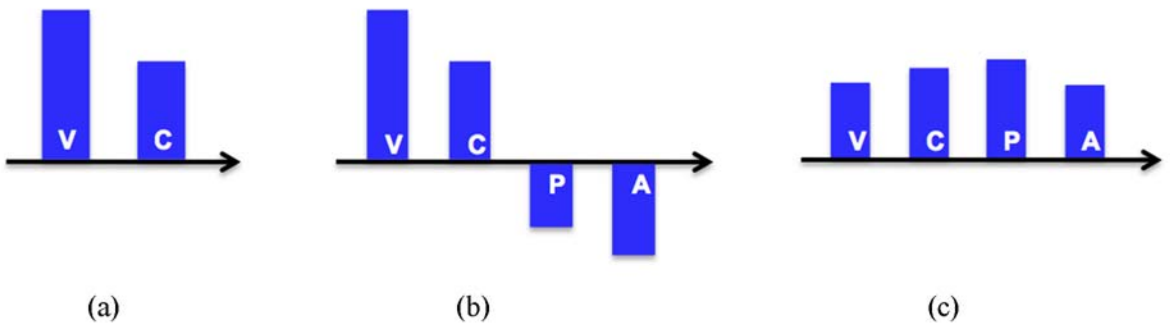


Figure 10. A visualisation of evaluation models for the TubeCorp's design projects

The over-accumulation of constraints decreased significantly the chance of success of the project and levels of learning. While the solutions were not being found, no real understanding of the causes was being produced. The strategy based on the segmentation offered more balanced project portfolio. Even though the value for each project was lower (Figure 10c), the combined value for each project was roughly the same (except increased complexity in logistics). But the risks in the exploration of the new designs were reduced since the projects were less ambitious and less constrained. More importantly, the projects allowed better learning opportunities since fewer interactions were introduced into the matrices: focused observations were possible.

4.7 Modelling the innovation field: Generating new design paths

The model of the last section allowed articulating specific projects with strong learning orientations. In parallel with the current development projects, exploratory learning projects can be used to reveal a finer structure of the innovation field rather than to focus on avoiding potentially challenging parameters in order to search for direct solutions and rapid convergence. One advantage of this approach would be to reduce the over-constraining of the coating solution, displacing the constraints towards a new set of parameters previously omitted.

Since the aim is to profit from learning opportunities, the interdependencies are not necessarily negative factors. Rather, they are opportunities allowing the study of various interactions for better understanding the structure of the underlying phenomena and offering the possibility to discover new parameters that would allow independencies or better control.

To be able to detect and activate such parameters, the intervention team has proceeded to the construction of a C-K mapping of the innovation setting based on the FRs and DPs discovered along the way, whether they were adopted and studied or rejected and discarded. Figure 11 gives a simplified overview of the concept space part of the C-K mapping, in order to illustrate the approach. The identified knowledge domains and the full version of the tree are omitted due to confidentiality reasons.

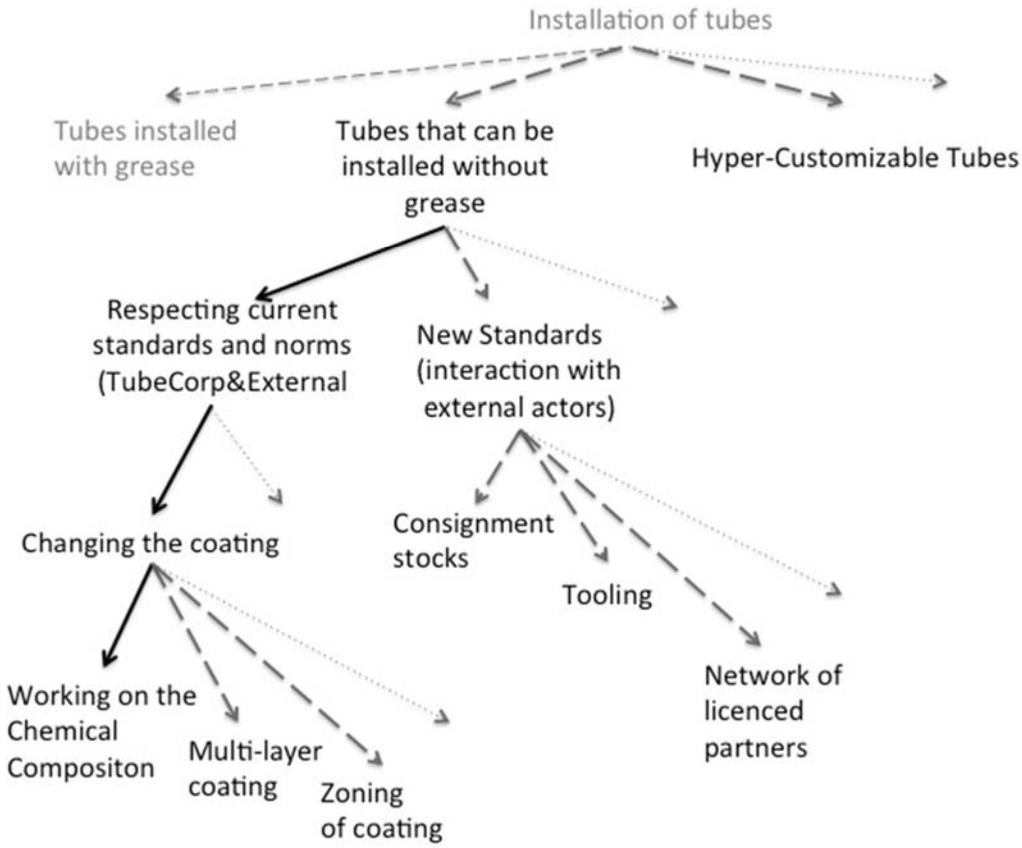


Figure 11. A simplified representation of C space for TubeCorp's tube installation activities

We can see on this representation a structured hierarchy of possible "projects". In figure 11, the current design path TubeCorp has taken has been depicted with non-dotted black lines. The mapping effort revealed several alternative formulations at all levels. For instance, it is possible to achieve a coating solution using multiple layers or the use of different coatings on different zones of the VAM architecture. Such orientations have the advantage of keeping intact the current use practices for the clients.

As soon as strategies that involves participation of clients both in design and use are considered, the number of DPs to be considered increases exponentially. Some of the possible partitions are Consignment Stocks (stocks where tubes can be pre-processed just before their delivery to the client), tooling (other combinations of tools than brush-grease) and partners operating closer to the final client that can be supported by TubeCorp's expertise and formation.

A new strategy that appears to be radically new for this field, hyper-customizable tube (one tube-one well) appears as a complementary partition. This is a high risk-high reward orientation, but its study may allow a refinement of the current practices e.g. regarding the qualification process and its speed.

Another possibility offered by this model is the diagnostic, prioritisation and resource planning it allows. Based on the numerous variant projects that have been constituted in the C space (some of which corresponding to actual projects), it is also possible to map the TubeCorp's knowledge space. For some of the FRs and DPs, TubeCorp has significant and reliable expertise, while for some of the detected knowledge areas the company has to either produce new knowledge (e.g. with exploratory learning projects) or to forge other partnerships or joint ventures with external companies (e.g. with companies such as ChemCorp). Furthermore, the company is able to mobilize now internal experts concerning the value of the generated design paths, building evaluation models and strategic priorities.

5. Impacting organizational innovation processes through theory-driven design models

The case of TubeCorp allows discussing several issues we have raised in the introduction and section 2. We have seen through out the case that several models were built successively to support innovation and organizational processes. During the intervention process, successive versions of the models were built often interacting with different stakeholders inside the company. The models allowed locating relevant experts, involving them in the process, making use of their opinions. Eventually, this evolution of models has enabled the evolution of the project (e.g. the segmentation of the products) and the broader vision within which the project took place (a renewal of strategic orientations and a questioning of the real innovation issues). The overall intervention process has indeed allowed producing new knowledge both about the project and the organisation through the models in a constructivist process.

It can be noted that the models had no claim to the reality and thus no uniqueness was sought. There were considered to be constructs and were used to advance understanding and enable action. Said in other terms, they were treated as rational myths. As we have pointed out at the end of section 2, from a constructivist perspective, the utility of models can be evaluated with respect to the difference they make in the trajectory of the organisational processes. In TubeCorp case, we have seen some clear indications of change, perceived as positive by the company. The perspective of both the marketing department and engineering department regarding the yet-to-exist product was deeply changed: from a single, all-powerful solution orientation the company has traditionally adopted, they moved, albeit with some difficulties, towards a new vision where, not only their current range of products, but also they way they approach this particular innovation field was significantly modified.

In addition to the conformity of our observations with modelling practice in the broader management and operations research field, there are some significant issues that are note-worthy from a Design Theory perspective. The models used during the intervention processes were for the most part Design Theory based models. Said in other terms, the models were instantiated from abstract and formal theories trying to capture salient and unique aspects of any design processes.

Axiomatic Design focuses on the dependency relationships between parameters and functions whereas C-K theory assumes no particular ontology. On the other hand, Axiomatic Design, as a tool, has the aim of evaluating the quality of design solutions, while, C-K theory offers support for a reasoning process aimed at generating design paths and associated knowledge domains. These distinctions and their effects were plainly visible during the intervention phase. Suh matrices were helpful in mapping the design domain (as currently considered by the TubeCorp) and revealing hidden interactions or problematic areas. They allowed better understanding the project objectives and uncovering the fact that there was over-accumulation of constraints on the current design solution. It also helped diagnosing differences in the design rationales held by TubeCorp and ChemCorp. Once the problems were revealed and main parameters of the domain mapped, C-K theory based representations allowed constructing a holistic view of the current innovation domain, generating several alternative paths and enabling strategic planning for present and future projects. The initial design project was expanded in new ways, while the missing knowledge to address these paths was identified.

From the case presented and the above analysis, it can be argued that models generated based on design theories have the specificity of dealing with unknown and novelty. As we have seen, the usefulness of models can be discussed with respect to their impact on the innovation and organizational processes. In the case of design models, the change of organizational processes has the potential to generate an evolution (a new understanding) of the structure of the targeted novelty and the strategy to deal with the unknown. Assuming that innovation can be seen as revising the identity of the objects (creating new object types and categories), this requires the revision (of the identity) of the organisation (if not the structure, at least, the way the activity and the projects are conceived by the participants of the organizational processes.) As shown in the particular case of TubeCorp, design models by interacting with the organisational structures has the potential to revise the identity of the organisation, enabling the revision of the identity of the objects.

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