# Innovation theory and the logic of generativity: from optimization to design, a new post-decisional paradigm in management science

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# Presented to EURAM 2016

# Innovation theory and the logic of generativity: from optimization to design, a new post-decisional paradigm in management science

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**Abstract (144 words)**

In this paper we contribute to show that innovation theory can today strongly contribute to the (re)foundation of management. Innovation theory is teared apart between the historical optimal-decision-making paradigm and the new perspective on creation. Still contemporary advances in design theory provide an integrated framework that accounts for decision *and*creation, their similarities and differences, and enables to introduce a relativity principle, the unknown (or the expected generativity), to account for the continuity from one activity to the other. We show how applying that general framework and that relativity principle can help extend decision-based models (decision under uncertainty, problem solving, combinatorics) and how this extension helps revisit basic managerial notions built on these models (risk management, knowledge management, coordination…). We conclude on some of the perspectives opened by this relativity principle for management.

# INNOVATION THEORY AND THE LOGIC OF GENERATIVITY: FROM OPTIMIZATION TO DESIGN, A NEW POST-DECISIONAL PARADIGM IN MANAGEMENT SCIENCE

Beyond every fashions and buzzwords, management science regularly progresses and produces new notions. Beyond this "normal science", many symptoms might indicate that a paradigm shift could be coming today in management: there is a crisis in management education (eg (Starkey, Hatchuel et Tempest 2004)); there are questions about management research methods and instruments, as if the phenomena were more and more difficult to observe and the propositions were too subtle to be easily proven; leading journal editors keep asking for more theoretical papers, as if theoretical grounds should be at least strengthened, or event rebuilt (see for instance editorials in JPIM); again and again the issue of relevance is raised by leaders, practitioners or voices of the society.

When it comes more specifically to innovation, the phenomena are even stronger. For instance: relying on the usual definition of innovation inherited from economics, we consider that an innovation is "an invention that found a market" – and we insist on the market issue… much more than the invention aspect. Innovation management research accepts usually that innovation consequences are profit, competitive position and, in the end, employment and growth. And we forget by the way that these are just "indirect" consequences: often innovators didn't necessarily seek profit and employment they "just" intended to launch a new product and/or a new service for this new service in itself, for its new uses, or event for the creation as such, for the "unknown" that they conquered. Engineers by car makers or aircraft integrators, designers by Alessi, artists, architects or craftsmen might all innovate not necessary "for profit and shareholder value" but simply to create new cars, aircrafts, coffee machines, buildings, transportation systems, furniture, smart objects, new sensations,… For them, it might be far enough to change fashion, techniques, ways of looking at things, uses, identity of objects, definitions of things,… deep changes that can occur without market success but not without a deep, smart, complex, demanding generativity endeavour. Hence, a need in innovation management to shake traditional disciplinary definitions to really grasp contemporary forms of collective creation.

Even more: innovation management also tells us paths to change the paradigm of management science: putting off the blinkers of the "market success", some studies in innovation management also insisted on key notions in innovation phenomena: creation, generativity, capacity to change the game, to create new values, new utility, new action means, new resources, new reasons for people to work together… Where the "old definition" insists on "what is known now", recent works insists on acting in the unknown and the emergent,… Beyond the critics to the old paradigm, innovation management can also help to refound a new paradigm in management science.

These results have brought strong arguments to show that innovation theory can today contribute to the refoundation of management:

1- even if innovation theory has not developed that much, the study of innovation phenomena (in multiple, varied fields: management, psychology, ethology, history…) has progressively led to develop formal models, in particular *design theory*, that now account for generative processes compellingly(Hatchuel et al. 2011; Epstein 1999).

2- to account for the new forms of collective actions that emerge precisely around these innovation phenomena, management science can't content with relying on the *decision paradigm*,which has long been one of its main roots. Studying these forms of generative collective action with a decision paradigm results in logical aporia and unconclusive empirical studies (see for instance (Hatchuel et al. 2010; Rogers, Hsueh et Gibbons 2005)).

3- by contrast, the study of these forms of generative action with *a post-decisional, generative paradigm* helps to deepen the foundations of management science andopens new paths for research. Moreover, since the generative paradigm includes and extends the decision paradigm, it helps to strengthen the decision roots without destroying them.

These propositions have been established (at least partially) by relying on empirical approaches: many works have already shown how innovation cases oblige to revise classical notions in management and/or propose new notions that take into account the generative logic that is inherent to innovation – see for instance the works on "managing as designing" (Boland et Collopy 2004), design approaches in strategy (Hatchuel et al. 2010), or critical works that underline unconclusiveness of traditional organizational approaches for innovative organizations (Damanpour et Aravind 2006),…

Still these results are often interpreted as showing the "great divide" between (radical) innovation and decision making. And this false evidence of a great divide tends to separate works on radical innovation and disciplinary approaches in HR, marketing or strategy. This "great divide" prevents to see how lessons learnt in radical innovation studies could bring insight to other works in management science.

In this paper we show that there is a continuity between decision-optimization and radical innovation – we keep the unique features of both activities, but we also show that both activities can be represented in the same framework and one can shift from one to the other by modifying one parameter of the theoretical framework, namely the generativity power (or, its dual facet: the unknowness level). We finally show how "generativity" can play the role of a "relativity" principle in management science.

In a first part we will show the issue of overcoming the great divide; in a second part we show how design theory is a unifying framework that accounts for decision and radical innovation, their similarities and differences, and enables to introduce a relativity principle, to account for the continuity from one activity to the other; in a third part we apply that general framework and that relativity principle to more specific formal models, that are underlying many works in decision paradigm: we show how relying on design theory, one can extend the model of decision making under uncertainty, the model of problem solving, and the model of combinatorics. We also show how this extension helps revisit basic managerial notions built on these models (risk management, knowledge management, coordination…). We conclude on some of the perspectives opened by this relativity principle for management.

## Part 1- the great divide – optimal decision making vs creativity

We first show the two paradigms in innovation management – decision paradigm and creation paradigm - and the issue of overcoming the great divide between them.

## 1- Decision paradigm in innovation management: historical breakthroughs

It is interesting to underline that many breakthrough obtained in the study of innovation management in the second part of the 20th century were based on the decision-optimization paradigm.

Regarding R&D management models, a first stream of research addresses new product development and planning (see for instance (Clark et Fujimoto 1991; Thomke et Fujimoto 2000)). Researchers have assimilated a new product development (NPD) project to a general project (like the project for organizational change or civil engineering, or event organization…) where the "production" activity is broadened to the production of data. "tasks" – ie steps in the planning- are not limited to production steps but are steps in the process of "data production". This way, the authors were able to transfer tools and techniques of operation research to innovation situations. The works discussed ways to manage project resources to meet product requirements in a reliable time. Budget, time and quality control relied on the measure of the drift from the optimal path in a PERT diagram. Knowing the tasks, the constraints (resource costs and availability,…), managing a project consists in finding the optimal path and be able to monitor and re-plan in case of drift (taking into account new resource constraints, taking into account an external shock,…). It relies on specific models and techniques that are derived from usual operations research techniques, in particular graphs theory and algorithm: critical path construction with PERT, multiple paths with resource and cost constraints (Gantt diagrams, PERT/Cost) and random events (Random PERT). Hence organizing the development process consists finally in mastering complex combinations. These works corresponded also to works on the organization of the development process: models like stage-gate(Cooper 1990), V-cycles or chain-linked organization(Kline et Rosenberg 1986) were based on gathering the right experts with the right knowledge to make the right decision taking into account relevant uncertainties at each development step. And in the strategy literature, researchers went as far as characterizing firms by their "combinative capabilities" – their capacity to combine pieces of knowledge into meaningful innovations and strategic actions (Kogut et Zander 1992).

Another stream of works addresses the economics evaluation of marketing and research activities. How to evaluate the value of money dedicated to research? Why should a company invest in knowledge production? Already in the end of the 19th century, a model emerged that quickly became so dominating that we often tend to think this is the only possible model: this money is invested to reduce uncertainty. One of the first authors working on this is no less than Charles S. Peirce at the time when he was working for the US Coast Survey (Peirce 1879) (reproduced in 1967 in Operations Research, Vol 15 n°4 pp. 643-648). This logic of risk reduction was progressively extended to other innovation skills: marketing was seen as a profession able to increase market knowledge to reduce market uncertainty. The role of research management or marketing management is modelled as the capacity to use research resources to get uncertainty reduction where it is most needed. Some researchers went as far as applying option pricing developed in finance (based on the theory of decision under uncertainty) to the pricing of so-called "real options"(Fredberg 2007; Perlitz, Peske et Schrank 1999).

A third stream of research deals with the economic evaluation of projects and project portfolio. How to evaluate the value of an NPD project with market and technical uncertainty? Assimilating an NPD project to an investment, it was possible to apply to NPD projects the tools and techniques developed for corporate investment: return on investment, net present value (NPV) and expected utility. Given a list of projects with known market and technical uncertainty, managing an NPD project portfolio hence consisted in choosing the projects ensuring the highest levels in NPV or expected utility. From a strategic point of view, many works analyse the tension between exploration projects and exploitation projects, referring to the seminal works of March (March 1991); here again: an analytical framework that is directly derived from decision making under "bounded rationality" conditions.

Hence innovation management techniques finally relied more or less implicitly on a set of techniques and models that all belong to the field of optimal choice (optimization on complex combinatorics (graphs), optimization in uncertainty situation) – hence the decision paradigm.

## 2- Ideation and creativity paradigm in innovation management

By contrast, many works have underlined that radical innovation requires imagination, ideation, creativity, dealing with the unknown – is forms of reasoning that are far from optimal choice.

For instance, creativity is born in psychological studies precisely as a way to characterize a form of intelligence that is different from IQ (Guilford 1950, 1959). For Guilford one can characterize IQ as the capacity to answer questions were there is one best answer whereas creativity is the capacity to answer questions where there is no one single solution – and one will appreciate fluency, flexibility and originality of the answers given (Torrance 1988). Many works in creativity management have then shown that managing collective creativity could not follow the usual rules of administrative management based on command, control and incentives to reach one specific goal (Amabile et al. 2005; Amabile 1998; Hargadon et Douglas 2001).

Regularly authors have shown that innovation obliges to change our view on management. Early on, in the 1960s, Burns and Stalker exhibit the "organic structure", by contrast with the "mechanical structure". The latter is characterized by clear work division, with local optimization and well-identified rules to aggregate results, hierarchical structure for command, control and communication. The "organic structure" (embodided in Burns & Stalker book by only case) raises actually a critical question: the determinants of creative behaviour with organizations are not described by the usual administrative language and they require another models. Van de Ven et al., based on the impressive "Minnesotta study" showed that the "innovation journey" is not planned and controlled towards one clear and well-specified goal – modelling the innovation journey requires alternative models. They insist for instance on the fact that learning in the innovation journey can not be modelled with the usual models of uncertainty reduction: in the usual "try and learn" models, action reduces uncertainty of well-identified outcomes but in the innovation journey, action reveals unexpected outcomes (Van de Ven 1986; Van de Ven et al. 1999). Meta-analysis of the determinants of the organizational determinants of innovation have largely confirmed that the usual descriptors (work division, span of control,…) can't explain the innovation success (Damanpour et Aravind 2006; Damanpour 1996). Many works have underlined the limits of "problem-driven" approaches, that can't account for "problem formulation" issues (Rittel et Webber 1972; Simon 1977)

These works led to consider that innovation management should rely on another paradigm, where emergence, creativity, new ideas, new knowledge, new "need-solution" pairs (Hippel et Krogh 2016) is the norm. This second paradigm is often described by metaphors and analogies. In an analogy with the work of the architect Franck Gehry, Boland & al. explain that managing should be considered as "designing", a capacity to remain in a "liquid state" instead of a cristal one (Boland Jr et al. 2008). Authors use the notions of "mapping", "framing", "guiding patterns", that appear as metaphors for a design strategy, a design rule or a brief (a classic practice in industrial design).

## 3- When the great divide limits our understanding of innovation – and management

In the last decade, new trends emerge in innovation management. Interestingly enough, many of these new trends tend to keep the optimization logic, by finding ways to improve the quality of decision. Let's take some examples among well-known streams of research:

- Open innovation builds on the assumption that internal R&D costs limit the quantity of knowledge that is available to find an optimal solution to a given problem. Open innovation (Chesbrough 2003) considers that relying on external resources enables to increase the quantity of ideas and knowledge at a reasonable cost or even at a lower cost than in a "closed innovation" model. Hence Open Innovation helps the firm to get a better solution at a lower cost to solve one given problem.

- Another example is the logic of platform and modularity (Gawer 2009): this strategy builds on the fact that markets are uncertain and fast evolving, so that an innovation strategy that would adapt to one particular demand is risky and innovators finally develop platforms and modules that help them to resist market uncertainty. As demonstrated by (Baldwin et Clark 2006, 2000), the logic of modularity is actually an option logic. It is an optimization logic in uncertainty situation.

- The ambidexterity approach deals with the balance between evolutionary and revolutionary changes in organizations (Tushman et O'Reilly III 1996), between exploitation and exploration in organizations (March 1991). Since "exploitation", in the sense of March, is no more than a form of a "search" strategy in which one does not choose the frequently used search routines but one uses rarely used one, one finally tends to interpret ambidexterity as a "search" that mixes to heuristics – finally a refinement of optimal decision making heuristic.

- Recent studies on managing risk in "unknown unknown" (unk unk) situations (eg (Loch, Solt et Bailey 2008)) aim at integrating unknown "state of the world" in the Savagian decision making theory (see p. 31). But this "unknown" states are finally modelled as uncertain states, hence remaining in the Savagian framework. And consequently the prototyping strategies in unk unk situations are modelled as uncertainty reduction strategies, based on "search" in complex probability spaces(Sommer et Loch 2004; Loch, Terwiesh et Thomke 2001).

Hence these four streams of research finally rely on the decision paradigm. But the paradigm also imposes limits:

- Research works have shown that the logic of "problem solving" is a critical limit to open innovation (Sieg, Wallin et von Krogh 2010). And empirical studies have shown that there are forms of open innovation that are not driven by optimal problem solving but by a more efficient exploration of the unknown (Agogué et al. 2015).

- Platforms are not only made for uncertainty reduction (Gawer et Cusumano 2014; Gawer 2009). There are also platforms that are created to improve collective exploration (Gawer 2014; Le Masson, Weil et Hatchuel 2009).

- As recently underlined by (Birkinshaw et Gupta 2013), ambidexterity should be understood as "an organization's capacity to address two organizationally incompatible objectives equally well" (p. 291) – hence ambidexterity is more than a compromise, it raises this issue of the organizational structure that enables a renewal of the collective creative capacities.

- Regarding the "unknown" literature: some papers have identified cases where collective innovation management really meets Loch assumption – it consists in changing the probability space – and not only in reducing uncertainty(Kokshagina, Le Masson et Weil 2015).

In all four cases, it appears that the optimal decision making paradigm is regularly used even for innovation management and even in cases where radical innovation is at stake. The optimal decision making paradigm brings actually intellectual frameworks and methods that help to (partially) characterize certain facets of the efficiency of innovation management processes and organizations. But it also limits the full understanding and the full analysis of these four forms of collective action (open innovation, platform, ambidexterity, managing the unknown).

### 4- research question and method

Hence our research question: can we establish a continuum that extends optimal decision making to collective creation? More precisely, the requirements are as follows:

1. the new framework should account for both optimal decision making and creation. We will show that contemporary design theory has this property.

2. the new framework should contain "parameters" that could explain the continuity from one extreme (pure optimal decision making) to the other (pure creation). This parameter would play the role of a "relativity" dimension.

This latter point has to be explained: With relativity theory in physics, physics theory is relative to the ratio between the nominal speed and light speed – for low speed, Newtonian theory is enough, for high speed, relativity theory is required. But the former is actually a simplified case of the latter. We are looking for similar notion in innovation management.

Our method is then as follows:

1- We rely on one very general theory of models of thought, that encompasses optimal decision-making. We will show that advances in *design theory* have led to propose a design theory that has this property.

2- We show how design theory enables to extend three specific models of thought that are related to optimal decision making: a model of optimal decision under uncertainty, a models of optimal complex problem solving, a model of decision based on combinatorics. More precisely we show that in each three cases, the unknown (or the expected generativity) is the critical, relativity parameter. We will show that the unknown (or conversely, the generativity) plays in management the same role that speed in physics. With the unknown, management notions become relativist. When unknowness (or expected generativity) is low, then the notion can be interpreted and worked in a decision paradigm; when the unknown (or expected generativity) increases, the design paradigm applies. And the former is a simplified case of the latter – in which the unknown (or expected generativity) is as negligible as is the ratio between nominal speed and light speed in Newtonian physics.

## Part 2: Design as a theoretical framework that extends optimal decision paradigm –generativity as relativity principle

### 1- Main features of the optimal decision paradigm

As underlined in (Buchanan et O'Connell 2006), a history of "decision making" could begin with prehistory! Still this is rather after world war II that models of "decision making" were progressively formalized and integrated into a general framework. Recent historians' works enabled to understand the movement of "rational choice" that unfold at the end of world war II and during Cold War (Erickson et al. 2013). One of the critical issues was to find models and algorithms that could account for rational decision making – in particular to be able to support or even control human decisions in the Cold War crisis situations, where human emotions and tensions threatened to lead to "irrational" choices (see (Erickson et al. 2013)). The conjunction of scientific breakthrough, political concern about rational and controlled choice and industrial needs for handling complex planning led to a tremendous research movement on "optimal choice", heavily funded by the US state and industrial companies, in famous institutions such as RAND Corporation, the Office Naval Researchor the Carnegie Institute of Technology, with extraordinary interactions between many disciplines (economics, political sciences, management, psychology,…)and involving among the most brilliant researchers of the time (John Nash, Herbert Simon, Charles Osgood, Thomas Schelling, Herman Kahn, Anatol Rapoport…).

It would be far beyond reach of this paper to make a history of the development of the decision paradigm since world war II – all the more useless that it was recently done by an international group of research (Erickson et al. 2013). We will just underline two movements: one the one hand works led to a "positive" movement of creation of theoretical frameworks, algorithms and methods related to optimal choice. For instance, in the 1950s, the development of the decision theory under uncertainty provided management with "the basis disciplines that underlie the field of business administration" – who said that? Bertrand Fow, the Director of Research of Harvard Business School in his preface to the reference book "applied statistical decision theory" of Raiffa & Schlaiffer (Raïffa 1968). And Raïffa and Schlaiffer explain that their own work is grounded on Savage 1954 book “the foundation of statistics” (Savage 1972) and Wald’s “Statistical Decision Function” (Wald 1950). The theory of statistical decision provided an integrated framework that could account for choice between known alternatives, taking into account uncertain events; moreover the models were able to put a clear value on uncertainty reduction endeavours (leading later to option theory and later real options). On the other hand, some researchers worked on situations were the set of alternatives was complex and highly combinatorial; in the stream of operation research, their works helped to determine the optimal path in complex combinatorial situations. The famous Simplex algorithm, invented by Dantzig in 1947, helped to solve complex problems by relying on linear programming.

One the other hand, some researchers addressed multiple critics to rational optimal choice models:. the grand fathers of management insisted on the limits of rational decision theory in real situations. Because of psychological or organizational biases, managers and companies were not able to make the “optimal” decision. Economics Nobel prize Herbert Simon built on the fact that human decision making was finally a “bounded rationality” (Simon 1955) so that human could only rely on “procedural rationality”, ie find heuristics and algorithms that might not lead to the “best” solution but to “satisfying” one. Hence a great consequence: the role of the executive was no more to choose the best solution but to organize the design of decision functions that would lead to more or less “satisfying” solutions. This paved the way to analysing the logics of routines in organizations, contrasting exploitation logics –where people rely on frequently used routines- and exploration –where people try rarely used routines (March 1991). In psychology, Kahneman & Tversky (Kahneman et Tversky 1979) (also Economics Nobel prize winners) underlined the biases introduced by heuristics and they open new paths to research on how to inhibit biased heuristics to favour better decision making processes. Research on collective decision making also underlined negative or positive effects of collective groups on decision (the group introduced biases in the process; or the group might help to overcome individual biases…). These critics paved the way to reference works in organizational design, organizational learning, action learning, strategic management,…

Interestingly enough these two movements – positive or critic- were anyway in the same decision making paradigm. Of course, critics tended to add some additional constraints to the general models (psychological bias, routines in search processes,…) but they kept the paradigm: the managers (or the teams, or the organizations) are not perfect decision makers – but still they are decision makers. They cannot find the optimal point, but still they are looking for this point taking into account their limited knowledge and their biases. And the dialectical movement of positive propositions and critics proved particularly fruitful for the development of theories, models and methods of optimal choice. These discoveries were often made in the field of management research or strongly contributed to its development (for instance the journal “management science” was created by Herbert Simon precisely as a means for collective research on these topics).

It appears finally that optimal decision paradigm finally has three facets: formal models – decision under uncertainty, problem solving in complex problem spaces, combinatorial decision making; a cognitive dimension, derived from the formal models (biases, heuristics,…) ; an organizational dimension, derived from the formal models and the cognitive dimension (information, knowledge, competences, work division, performance,…).

We now focus more precisely on the formal models. Models of optimal choice share the same axiomatic structure: given one actor (or collective actor), who is able to acquire knowledge, it is confronted to a problem space, made by a set of elementary actions, constraints on these actions and a utility function associated to these actions, the actor looks for algorithms to find the most satisfying combination of actions that meets the constraints and reaches a satisfying utility level. Theory of decision under uncertainty (Wald, Savage, Raïffa), is one particular case (where the problem space is not too complex, so that the alternatives can be easily enumerated; and the utility calculus takes uncertainty into account). General problem solving (Simon) is another particular case, where the problem space has a so complex structure that it is impossible to enumerate all solutions (typically: winning at chess play). And we have powerful results:

1- following Wald:

- given a set D of alternatives δ,
- given a set Θ of states of nature $\theta$, with a-priori density $\mu(\theta)$,
- given a source of information on θ modelled as a sample $X_1 \ldots X_n$ of a random variable $X$ with density function $f(x, \theta)$ and a related sample likelihood $L(x_1 \ldots x_n, \theta)$,
- given a cost function $C(\theta, \delta)$ associated to each pair $(\theta, \delta)$,
- we are looking for the best choice function ψ that relates each particular sample $\underline{x} = (x_1, \ldots x_n)$ to a decision δ of D (more precisely: to a probability density $\lambda(\delta)$ defined for each $\delta$ of D) and optimizes the cost expectation:

$$E(C) = r(\mu,\psi) = \int_{R^n \times D \times \Theta} C(\theta,\delta)\, \lambda_{\underline{x}}(\delta)\, L(\underline{x},\theta)\, \mu(\theta)\, d\delta\, d\underline{x}\, d\theta \qquad (1)$$

- according to Wald: there is always a solution ψ0 such that:

$$r(\mu,\psi_0) \le r(\mu,\psi) \quad \forall \psi$$

This result is extraordinary general: there is always an optimal choice function – whatever the learning capacities L, whatever the a-priori belief on states of nature, whatever the set of alternatives, whatever the cost.

2- following general problem solving: even for very complex cases, there are powerful algorithms, like Branch and Bound, that enable to find a solution – you only need to be able to generate a solution by progressive separation and to be able to evaluate subsets of solutions (which is more than just being able to evaluate one individual solution). Here again, this is a very powerful algorithm, very generic, relevant for complex cases where it is not possible to describe all alternatives.

These works have also clarified the conditions under which such results are valid – and here again we have relatively generic results: the order of preferences should follow some generic logic (transitive rules) (Nobel prize Maurice Allais has shown that these transitive rules are far from self-evident, with his famous example, today included in the last versions of Savage's book)(Savage 1972); more generally the elements have to build an integrated framework with well-defined relationships between each parameters of the decision problem (eg partial order in branch and bound,…).

**2- Design theory: a theory of generativity**

Models of generativity also share common elements – (Hatchuel, Weil et Le Masson 2013) describes it as the ontology of design theory:

- there is knowledge, and in knowledge there is dynamic frontier between invariant ontologies (eg universal laws) and designed ontologies (where definitions are revised, extra-knowledge is added…).
- there are "voids" in knowledge, which are not uncertainty or "lack of knowledge about something that exists" but unknown entities which existence requires design work.
- There is a process for the formation of new entities (a process that is described in formal language – (Hatchuel, Weil et Le Masson 2013) notes that "'idea generation', 'problem finding' or 'serendipity' are only images or elements of more complex cognitive processes").
- And there is a mechanism to account for the preservation of meaning and knowledge reordering.

The generativity logic is at the heart of design theory: the models describe how the new (the unknown) can emerge from the known (the knowledge base), and how this newly known can be integrated to the previously known. To underline the difference: decision making begins with a set of alternatives that is already generated (or the process of generation is actually a combination built on known building blocks), whereas design *finishes* when an alternative that was initially unknown is considered as known (or as constructible by combination).

Just like decision theory clarifies the conditions for optimal decision making models, design theory clarifies the conditions for generativity. Note that it is not self-evident that there is any condition! Intuitively we tend to consider that generativity is a "free space", the only limits that one tends to mention are cognitive ones (fixations). However recent works on design theory have helped clarify formal conditions for generativity. This is called the splitting condition(Le Masson, Hatchuel et Weil 2013; Hatchuel, Weil et Le Masson 2013). Without going into details, according to the splitting condition, a knowledge base allows generative processes only if the knowledge base is not deterministic (in any situation, there is always at least two alternatives) and not modular (no building block can be added without influencing the rest of the design). This means that there must be some forms of "independence" in the knowledge base.

Here again it is interesting to underline the deep difference between decision making and design: decision making is based on interdependences – in the integrated knowledge base, interdependences help to combine elements and help to reduce uncertainty on states of nature by sampling methods. In the world of decision making, independence has no value: if variables are independent, sampling one variable won't tell anything on the other; if components are independent, there combination has no meaning. By contrast, independence appears as the critical (unique, necessary, indispensible) resource for generativity.

As we described in the first part, decision theory was built as a reference that helped to analyse empirical decision making processes (individuals, groups; in real situations or in experimental situations,...). And the questions were: is there a bias? If yes, what is the cause? Can this bias be addressed? These questions were basically the questions that drove the research on the “good decision maker”, the decision making processes, the role of routines in decision processes, the psychological biases, leadership, etc.

Design theory plays exactly the same role to analyse generativity processes. Suppose that one team (or one creative designer, or one division, one company,...) comes with a set of proposals to address an innovation issue. The same questions can be raised (see figure below): is there a bias in this set of propositions? If yes what is the cause? How can it be addressed? Note that one issue in this type of study is to measure the bias towards the theoretical reference. Decision theory helped to define the theoretically ideal choice; in generativity, design theory provides the reference.

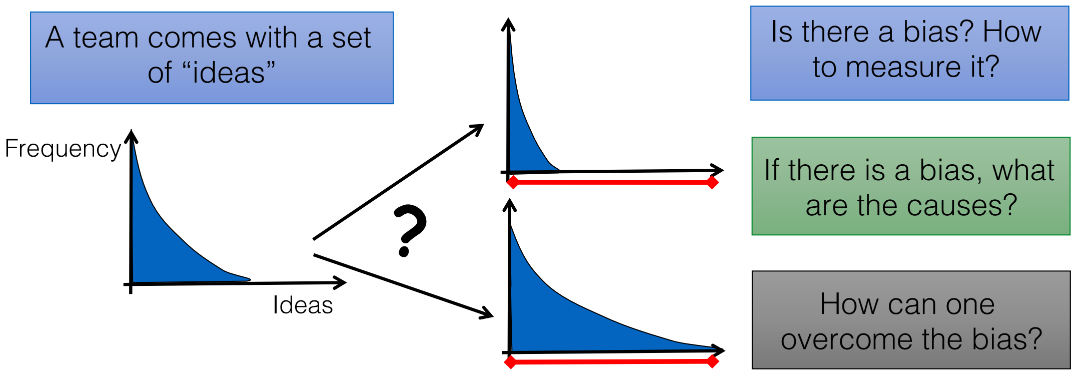


**Figure 1: empirical research with design theory**

Many works follow this pattern, from an individual cognition perspective (see for instance (Agogué et al. 2014)) to a collective one or even to organizational issues.

## 3- Design theory as an extension of optimal decision – generativity as a relativity principle

As underlined above: design theory accounts for generativity processes, hence it is a relevant model for the study of radical innovation. It also encompasses the creativity paradigm that we mention in part 1. And its formal properties help to build cognitive approaches and organizational approaches on it.

On the other hand, design theory also encompasses optimal decision making. This has been shown formally in other academic papers and books (Hatchuel 2002; Dorst 2006; Le Masson, Weil et Hatchuel 2010). They also show that design theory can be assimilated to optimal decision making when *no extensions* are expected, ie there is no expected generativity, or, to say it in another way: the design process will explore the unkown in an extremely limited way, in a negligible proportion. In that particular case, all ontologies are invariants, there are no holes in the knowledge base which is now integrated (just as in the optimal choice paradigm) and the process of designing becomes the process of building one optimal solution in a problem space (that might include uncertainty).

Hence, expected generativity or the unknown appear as the critical parameter that enables to describe in the same theory the situations that are very close to optimal decision making and the ones that are, by contrast, closer to radical innovation and creation.

## Part 3: Extending classical models of optimal decision with design theory

We will now show how design theory can play the role of a paradigm in innovation management. We will test this proposition on three optimal choice models that have given birth to critical notions in innovation management. On each model we show: 1- that we can extend the optimal choice model to design situations, just by increasing the unknowness (or the generativity) while relying on a design paradigm; 2- the critical notions related to each of these models are kept but enriched in the extension process from optimal choice to design theory.

The three models are:

1. decision under uncertainty – this model is the root of many works on risk management, on knowledge management and on the value of information

2. general problem solving – this model is the root of many works on the role of constraints in building solutions, on monitoring the elaboration of solutions and on strategic management

3. combinatorics – this family of models is the root of many works on the analysis of products and objects, on the role of expertise in organizations and on the strategic management of resources.

In each case we illustrate the shift by simple examples and we show the consequences on management notions.

### 1- Beyond decision under uncertainty: revisiting risks, knowledge and the value of information

Derived from Wald and Savage work on decision theory under uncertainty, Raïffa developed decision tree under uncertainty(Raïffa 1968). Given a set of alternatives, states of natures and beliefs on these states of nature, it is possible to compute the expected utility of each alternatives and choose the best one (see example in the figure below). This is the basis for the techniques of investment evaluation and decision and for portfolio management.

Moreover, it is possible to consider additional alternatives that consist in learning on the states of nature and to compute the value of the alternative (see example below), hence to reduce uncertainty. This reduction depends on the learning performance, that is defined by conditional probability that a certain measure is done for a given state of nature ($P(U_i/\theta_j)$). And this grounds the foundation for the techniques to evaluate research activities or marketing studies. It is possible to compute the cost acceptable for such study, depending on their precision. Note that, self-evidently, an instrument that aims at reducing uncertainty has to be strongly correlated to the variable to be analysed (weather forecast are all the more valuable that they predict weather with very limited errors). These instruments are the basis for real option techniques, and more generally for risk management.

Still this apparently wide-ranging paradigm has some intrinsic limits. Let's begin by reminding of one old joke. The shadoks are creatures invented by French cartoonist Jacques Rouxel in the 60s-70s. When building a rocket to Mars, they rely on mottos derived from decision making under uncertainty and the logic of 'try and learn': "When one tries continuously, one ends up succeeding. Thus, the more one fails, the greater the chance that it will work" and a direct application: "since Shadoks computed that their rocket has one chance out of one million to succeed, they rush failing the 999 999 first tries." – this far-fetched approach underlines that learning and trial in innovation is not necessarily related to just identifying the working solution but precisely leads to deeply change the artefacts so that finally the rocket works *at each launch*, ie so that the probability space has changed and evolved! By contrast, Shadoks underline that an innovator might be "transforming" the probability space! This corresponds to Loch initial intuition (Loch, Solt et Bailey 2008): decision under uncertainty depends on a probability space describing all the possible states of the world and their probability; but in case of "unk unk", innovation precisely might lead to create one or several new state(s) – unheard of, unimagined before. Since the decision making framework requires that states of nature are known, strictly speaking, the "emergence" of this new state can not be modelled in a decision making framework. But it can be modelled in a design framework.

Even more – consider the example in the figure below. The first figure illustrates an archetypal situation of optimal choice under uncertainty with the possibility to "learn" during the process, in order to reduce uncertainty.

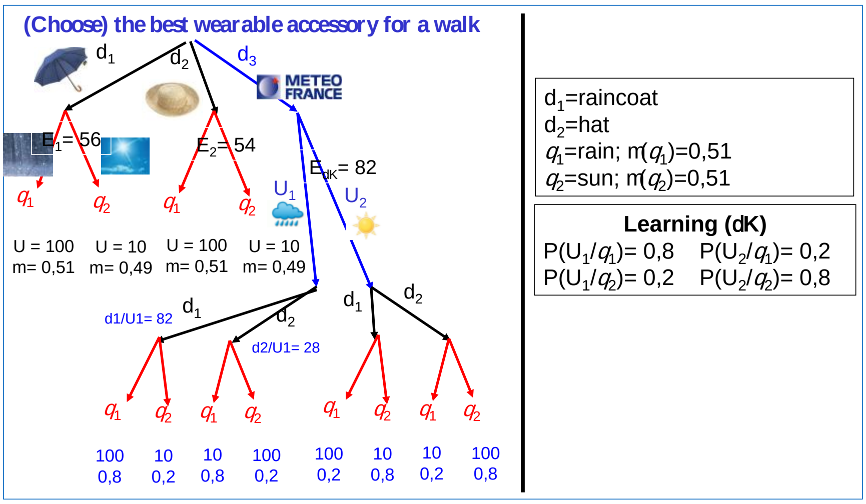


**Figure 2: example of decision tree under uncertainty**. On the right hand-side: the basic hypothesis (alternatives: choose a raincoat for a walk vs choose a hat for a walk, states of natures = rain during the walk vs sun during the walk, beliefs = 50% chance that it will rain, 50% that it will be sunny); on the left hand-side, far left: d1 and d2 : portfolio management (choose between d1 and d2); in the middle: d3, an alternative to reduce uncertainty before choosing d1 or d2 consists in taking time to read weather forecast – weather forecast is not ideal and the precision of the instrument is given in the data on the right hand-side: the forecast of rain is 80% when it will rain, the forecast of sun is then 20% when it will rain (and vice-versa)

In this archetypal case, generativity begins simply by wondering: "what would be an alternative that would be better than all known alternatives?" In the case of the raincoat vshat decision, this would be an alternative that is as good as a raincoat when it rains and as good as a hat when it is sunny (see figure below). This "alternative" is partially unknown (as such it is not an alternative as $d_1$, $d_2$ or $d_3$) and still it is possible to build on it: it has a value for action! For instance it can push to explore on uses in mobility, on textiles, on protecting against rain,... And it is even possible to compute elements for the value of this solution – not as a result but as a target: to be acceptable, the value distribution of the solution should be, for instance, 100 in each case.

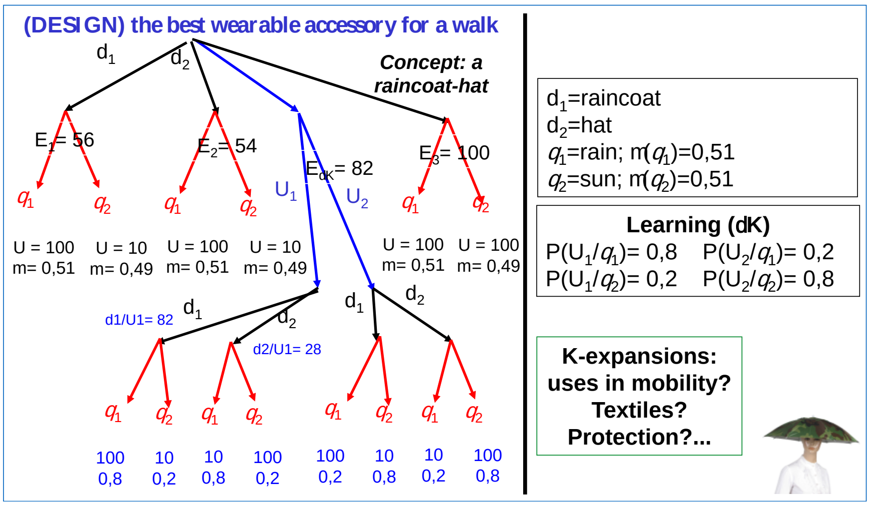


**Figure 3: decision tree with an unknown "alternative"**

This very simple case shows the logic of generativity: *there is an unknown*, this unknown is *desirable and its potential value can be expressed*. Note that coming back to Wald theory (see equation (1) above), it is possible to systematically express an unknown "alternative" for each decision making problem! For each decision making problem, instead of looking for the best decision function, one can also try to design $d_{n+1}$ such that:

$$\forall i=1\ldots n, \forall \mu \int_Q C(\theta, d_{n+1})\, \mu(\theta)d\theta < \int_Q C(\theta, d_i)\, \mu(\theta)d\theta \qquad (2)$$

What is the logic of "trial" in this situation? In the case of the raincoat-hat, the trial consists in designing an alternative that is independent of the weather (rain or sun). More generally, progress in design theory have shown that trial in a design perspective consists in designing alternatives that are *independent* of the states of nature. This is extremely counterintuitive: whereas trial for uncertainty reduction aims at being strongly correlated to states of nature, trials in design looks for independence from states of nature – the exact contrary! Geometrically, trials for uncertainty reduction are, ideally, in the space of the states of nature; trials for design are, ideally, orthogonal, to the states of nature!

Beyond the paradox, this underlines a deep logic of the value of knowledge in generativity. In uncertainty (and more generally in information theory), knowledge is usefull if it is correlated to other variables – through correlation, the acquired information will bring knowledge on the variable of interest. By contrast in design, knowledge is useful if it is *not* correlated to any known variable – because through independence, the information is different from all already available information.

These basic results have direct consequences for classics in management - consequences that have been already described by many research works:

- For *risk management*: action does not only consist in reducing risk; it also consists in designing alternatives that enable to be independent from known risks! This apparently paradoxical path is actually quite well-known and practiced in innovation management when designers invent techniques that are generic, ie these techniques are designed to be valid on a large number of markets – so that, even if the probability of success is very low for each market the probability that at least one market emerges becomes very high! (Kokshagina, Le Masson et Weil 2015)
- For *knowledge management and creativity*: crossing the boarder from decision making to generativity, we didn't forget what we knew! Contrary to misleading assumptions that one should begin on a blank sheet, we see how the structure of the known actually helps to *formulate* relevant unknown and to reveal holes in knowledge. The unknown emerges from the known. If there is less knowledge at the beginning, then the design process will be less challenging.
- For *the value of information in the generativity paradigm*: we reminded that decision making under uncertainty is also a theory of the value of learning. Crossing the boarder between decision and design, it appears that learning is also highly relevant – but its logic is different. In decision making, one learns with instruments that are correlated to the variables whose standard deviation have to be reduced; in design, one learns on variables that are independent from all variables of interest! In decision theory, the value of information is proportional to uncertainty reduction – so that independent information has no value; in design theory, the value of information lies in being independent from what is already known.

**Table 1: extending the decision under uncertainty**

| Extending… | Keep | From Decision to design | From design back to decision |
|---|---|---|---|
| **Decision making under uncertainty** | Risk management | From uncertainty reduction to regenerate the space of probability | Structure a probability space with better expected utility! |
| | Knowledge management | From integrated knowledge algebra, without holes to identify holes and create knowledge | Reduce holes to create integrated knowledge structures enabling decision |
| | Value of information | From the value of interdependences to the value of independences | Design creates new interdependences that enable better predictions |

## 2- Beyond problem solving: revisiting constraints, strategy and leadership

A second critical stream of work in the decision making paradigm is *problem solving*, ie the capacity to identify the best solution (or at least a satisfying one) in a complex problem space. In such complex problem space, it is impossible to enumerate all individual solutions; hence the idea of one paradigmatic algorithm, Branch and Bound (B&B is the root of the programs developed by Newell and Simon in their General Problem Solver research program): in the set of all alternatives, separate sub-set of solutions and, knowing the separation criteria, evaluate directly the whole subset (and not individual solutions). Then separate again the most promising subset, and so on.

This algorithm tends to prune the (too large) set of possible solutions to find the optimal solution. It is efficient and very generic. Still it works only if the users dispose of knowledge for separation and knowledge for evaluation.

This very generic algorithm is particularly useful for many industrial design issues (project planning, logistics, production,…). It is also the paradigm behind many management debates: management being assimilated to goal optimization under constraints, the problem solving paradigm helps to raise questions: how can one separate complex problems into subproblems? What is the evaluation function to evaluate partial solutions? More generally, what are the organizational forms that are adapted to problem solving? Research works have uncovered the difficulty to take into account all the constraints, raising the issue of expertise, the management of expertise in companies and the access to external expertise (absorptive capacity, open innovation). Researchers have also worked on biases: organizations will favor some separation or evaluation criteria, whereas separation and evaluation criteria depend on the type of problem – hence a risk of routinization, in which organizations member favor the exploitation of existing routine instead of using new routines in a more exploratory mode; this provokes bias in decision making. And the role of management becomes precisely to evaluate different separations and evaluations functions to increase overall performance. Hence works on leadership for optimal problem solving. The problem solving model finally helped to frame many management issues.

Still, here again this is a famous joke – the story says that, for an oral exam, a physic professor asked a young student (said to be Nils Bohr, which is actually not true and not important for our point) to solve the following problem: "how to measure the height of a tall building using a barometer?". The professor expected a solution based on the relationship between Pressure and Altitude. But the student proposed many other solutions like: "Take the barometer to the top of the building, attach a long rope to it, lower the barometer to the street and then bring it up, measuring the length of the rope. The length of the rope is the height of the building." Or: "take the barometer to the basement and knock on the superintendent's door. When the superintendent answers, you speak to him as follows: "Mr. Superintendent, here I have a fine barometer. If you tell me the height of this building, I will give you this barometer". Apparently the "problem" was well-framed and should be solved in a direct way, relying on known laws and constraints. But the student invents original solutions by relying on properties of the objects that are out of the frame of the problem: the barometer is not only a system to measure pressure, it also has a mass, it has a value,… In innovation as well, the innovator will play on neglected dimensions of objects or even invent new dimensions of objects – like smart phone functions that are not limited to phone calls…

Actually, in the problem solving framework, the "barometer problem" provokes a double surprise:

1- on the one hand, the "student" addresses an "impossible" problem: the initial problem was "measure the height of a tall building with a barometer – the "student" actually adds "…without measuring pressure". In the initial problem, the solver had to relate pressure and height using one relationship between pressure and altitude; with the refined formulation, it is not self-evident to say whether there is solution in the solution space or whether the solution space is empty. The added "constraint", "without measuring pressure", makes emerge an undecidable proposition.

2- It also appears that some objects in the problem (barometer, building) can have "unexpected" properties. A barometer is not necessarily an object for measuring pressure, it can for instance have value to be a reward for the building's superintendent.

The example reveals a surprising "strategy" related to generativity: whereas decision paradigm consists in finding one optimal solution in a non-empty solution space by using available action means, generativity consists in "closing" self-evident solutions spaces to force the emergence of new action means! Note that the hen's egg case described above is precisely one more elaborated case following this logic: on the one hand, the problem solving logic is applied – one generates the restrictive solutions in the following way: the "hen's egg fall" becomes: "avoid that a fragile object breaks by falling" and this leads to three main types of solution: damping the shock, protecting the egg or slowing the fall; on the other hand, these first solutions are detailed and this reveals degrees of freedom, that can be closed by adding constraints such as "without any additional device", "by using a living animal", etc. This leads to identify new action means. Moreover, in this process, "constraints" are combined and design theory has shown that there might appear a partial order based on constraints, just as there is a partial order through the separation process in Branch and Bound. The result is that the tree of alternatives of Branch and Bound becomes a tree in the unknown; hence a paradoxical result obtained by design theory: there is structure of the unknown.

This implies, again, deep changes in action models – changes that have been already anticipated by many research works:

- *Constraints in action*: in the decision paradigm, "constraint" means less degrees of freedom; it also means progressive definition of the solution (adding constraints after constraints helps to define the final solution); in the design paradigm, a constraint also becomes generative (Arrighi, Le Masson et Weil 2015b, a; Hatchuel et Klasing Chen 2015) – it enables to go out of the solution space; and it obliges to revise (expand) the set of actions means.
- *Monitoring projects*: in branch & bound algorithm, leadership consists in organizing separation and evaluation steps, and avoiding too narrow exploitation based on well-known routines. In a generativity perspective, leadership consists in adding constraints to "close" solutions spaces to push people to explore the unknown and identify new facets and paths.
- *Strategy*: just as they are strategies to explore a solution space (depth first, breadth first, simulated annealing to avoid local optima, etc.), there might be strategies to explore the unknown. Of course the strategic logic seems different: "close self-evident solution spaces", "stimulate the emergence of new action means" are the objectives. But this does not mean that any strategic monitoring is impossible. On the contrary, the logic of "closing solution spaces" can be tuned and iterated. Since there is a partial order in the unknown, a strategy can be built on it (again: steepest first or breadth first). Some authors have even proposed methods to extend Branch and Bound to design situations by a) adding an evaluation function that measures whether the solution space is, as in decision paradigm, non-empty; or whether it is undecidable; b) depending on the answer, it either launches a classical optimization procedure or launches the exploration to create knowledge (Kroll, Le Masson et Weil 2014).

**Table 2: extending problem solving**

| Extending… | Keep | From Decision to design | From design back to decision |
|---|---|---|---|
| **Problem solving** | constraint | From constraint as restriction to generative constraint | Build "restrictive constraints" that enable fast convergence |
| | Leadership and project monitoring | From speeding up optimization process to forcing "out of the box" | Generate a problem space with favorable convergence |
| | Strategy | From 'satisfying' & routines to capacity to tune generativity | Generate robust routines |

### c) Beyond Combinatorics: revisiting the dynamics of objects, of disciplines and ecosystems

The paradigm of optimal decision has also given birth to many works on combinatorics, leading to master more and more complex combinations, for instance through artificial intelligence, expert systems, neural networks or evolutionary algorithms. These models combine elements of solutions into comprehensive solutions, they evaluate each solution according to an objective function, and depending on the performance, they recombine the elements of solutions.

Just like problem solving or decision making, one should remind of these models being heavily used for instance in industrial engineering (today: image or speech recognition, contemporary CRM through targeted adds,…). Beyond these applications, the model also led to frame some management issues: following the idea that performance is in combination, authors defined the firm as a set of "combinative capabilities" (Kogut et Zander 1992), leaders are in charge of crossing expertise by organizing cross-functional teams, innovation consists in organizing serendipity, ie the random, unexpected combination of skills, etc. In strategic analysis and strategic management, industrial dynamics are modelled as evolutionary processes in which firms realize successful or less successful "genes" combinations.

In this model, Lego appear as the archetype of the combination logic – all blocks can be combined, it is possible to evaluate the final solution. Lego building can be more or less efficient or even "original": the combinations are more or less sophisticated, refined, etc… inside the algebra of all possible combinations. However, the Swedish photograph Erik Johansson has been revisiting M. C. Escher 'impossible construction' by using Lego. In particular he created a shape that is done with lego blocks but is impossible with (physical) lego blocks. This picture illustrates in a very powerful way the limit of the combinatorics models for innovation: in a world of lego, many combinations are possible, but the innovator might go beyond combinations by creating something that is a made with lego but is beyond all the (physical) combinations of lego. Innovation can be like this: combining old pieces of knowledge so as to create an artifact that is of course made of known pieces but goes beyond all combinations of the known pieces.

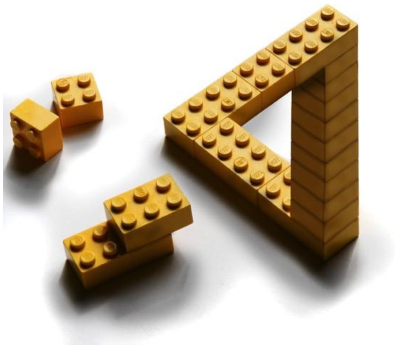

**Figure 4: Escher lego - Erik Johansson**

Hence it raises a question: how is it possible to combine basic, known elements in such a way that the final piece is different from all known and predictable combinations? How can combinatorics become generative – whereas it is often marked by a closed world logic? Actually the Escher lego just illustrates the *contemporary* models of generative combinatorics: evolutionary robotics for instance has developed evolutionary algorithms based no more on convergence towards an objective but based on organized divergence – so called "novelty driven" algorithm. In set theory, Forcing is a technique to create new models of sets by combining features of the initial model of sets. These recent works bring two insights(Hatchuel, Weil et Le Masson 2013):

1- it is possible to use the combination techniques to go "out of the box" – and not only to identify one particular point inside the box.

2- not all knowledge structures are adapted to generative combinatorics. As shown in the previous part (part 2.2), the structure of knowledge should be very specific. To simplify: there has to be some independences in knowledge.

This extension of combinatorics has also implications for management:

- Regarding the *objects* (products, services, competences,…): if combinatorics becomes generative, if algebras can be extended, then the set of objects is in constant evolutions, with regular creation of new object identities. Over time what is called a phone is strongly evolving – which is quite self evident- but this is also true for vacuum cleaner, a tooth brush, or a bike! The world of objects might be inherently generative. In the decision paradigm, we need to impose ex ante and stable definitions of things; in the design paradigm, we can accept changing identity of objects - obtained by an extended logic of combinations that goes from closed combinations to generative ones.

- This has consequences for *domain expertise*: the movement of generative combination regularly changes the models; when new entities emerge, it means that the whole set of products and related knowledge (skills, competences, disciplines,…) should be reordered to take into account the new entities and, above all, the combinations of the new entity with all "old" entities. In design paradigm, ontologies are not stable – they are designed and redesigned. Stability is just a temporary state.

- The logic of independence in knowledge structures induces *surprising leadership and strategies:* for instance the leader has to organize independence (and not only cross-functional logics). He has to organize differentiation and autonomy of skills – before organizing new contacts, later. The strategy consists in looking for partners that are not "complementary" but first of all, "independent". Organizing constantly evolving independences implies a logic at ecosystem level, and the development of completely new ways to deal with common unknown, their exploration and the critical issue of the appropriation – or their non-appropriation.

**Table 3: extending combinatorics**

| Extending… | Keep | From Decision to design | From design back to decision |
|---|---|---|---|
| **Combinatoric** | Objects | From a fixed algebra to a moving reference (for market analyzes, intelligence…) | Design algebra – eg: generic techniques that enable combinations. |
| | Assets | From assets as ontology to assets as capacity to restructure ontologies | A capacity to stabilize an ontology |
| | Strategic management of resources | From strategy based on core competences and specific assets to strategy based on re-oredering of things | Organize the regeneration of resources. |

## Part 4 –Conclusion and further research

In this paper we rely on design theory to propose the "unknown" as a relativity principle to bridge the gap between the optimal decision paradigm and the logic of creation in management. We showed that this relativity principle paves many paths to revisit basic notions in innovation management. It appeared as integrative of many research works already done in innovation management.

This formal approach is coherent with many works based on empirical approaches. It also call for empirical investigation – the design paradigm helps to formulate new and original hypotheses and, hence, original empirical research. Of course this (already) supports research in creative professions, creative firms of design-oriented organizations. More generally it calls for thorough investigations on collective action based on creation logics.

This formal approach can also nurture a renewal of education and teaching – for scholars, students and practitioners, it is more and more needed to understand the formal models of the design paradigm – not only "understand": also apply and prolong them in action!

Finally, understanding and formalizing these logics of creation also enables to give to "creation" a full "autonomy" .(Castoriadis 1987). Hidden behind optimization and decision making, creation tended to be interpreted as a means for utility maximization. Formal models show that there can be an *intrinsic logic of creation* – for an individual, a group, an institution or even a society. In this perspective, relying on a design paradigm, management science is in a position to better analyze the processes, to better identify new forms of collective action, to better educate citizens and actors of these new forms of action. Relying on a design paradigm, it is possible to avoid the trap of "heteronomy" – the over-interpretation of these logics by metaphysical principles such as rational utility maximization. Relying on the design paradigm, management could better participate to the invention of an "autonomous" society.

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