Planning technology maturation by exploration of useful problems in markets: The case of innovative startups

Alexandre Bekhradi

université PARIS-SACLAY

CentraleSupélec

NNT : 2018SACLE035

Thèse de doctorat

Planning technology maturation by exploration of useful problems in markets:
The case of innovative startups

Planification de la maturation d'une technologie par l'exploration des problèmes utiles sur les marchés :
Le cas des startups innovantes

Thèse de doctorat de l'Université Paris-Saclay
préparée à CentraleSupélec

École doctorale n° 573 Interfaces : approches interdisciplinaires, fondements, applications et innovation (Interfaces)
Spécialité de doctorat : sciences et technologies industrielles

Thèse présentée et soutenue à Gif sur Yvette, le 11 décembre 2018, par

Alexandre Bekhradi

Composition du Jury (par ordre alphabétique) :

Vincent Boly Professeur des Universités, Université de Lorraine	Rapporteur
Gaetano Cascini Professor, Politecnico di Milano	Rapporteur
François Cluzel Maître de Conférences, CentraleSupélec	Co-encadrant
Ola Isaksson Professor, Chalmers University of Technology	Président du jury
Michael Kokkolaras Professor, McGill University	Examinateur
François Moreau Chef de service, Ville de Paris	Invité
Bernard Yannou Professeur des Université, CentraleSupélec	Directeur de thèse
Gwenola Yannou-Le Bris Maître de Conférences, AgroParisTech	Examinatrice

Abstract

Technology-oriented innovative startups must conduct extensive experiments to gather sufficient proofs of value, so that they may reduce uncertainties before the launch of their products and services on the market. Despite their limited resources, the experiments conducted by startups are often random, loop-based and consequently time and resource consuming. Hence, startups need solutions to help them better planning their technology maturation and identifying market opportunities. It is in the context that the current research is carried out.

First, a literature review is conducted in the fields of engineering design, technology management and innovation management. This review suggests that the existing methods and tools fail to provide accurate and quantitative roadmaps to conduct relevant experiments. Second, this research surveys the design and testing practices of 60 innovative startups in the context of the City of Paris. This investigation reveals that despite the use of popular innovation methods such as Business Model Canvas (BMC) and Lean Startup, startups have no practical tools for specifying and planning experiments, nor for efficiently using their resources.

Therefore, this research makes the following three contributions. First, the BMC tool is combined with quantified value buckets (opportunities) and innovativeness indicators in order to make sure that the value offer is effective and significant. Second, a Design by Usage-based Experimentation (DUE) methodology is proposed to help screening the whole set of potential markets and to identify the main technology properties that need to be improved through experiments. Third, a quantitative methodology called RITHM (Roadmapping Investments in TecHnology and Market) is proposed to optimize the set of experiments, so that they result in the maturation of a technology to reach the most profitable markets. The relevance of the proposed methodologies is assessed through their application to technology-oriented innovative startups and also through expert validation. Finally, this research concludes that it is possible, with more effective and economical R&D strategies, to better define experiment roadmaps and better steer technological startup investment.

This research may significantly support the decision-making process of various actors: entrepreneurs, who need to justify R&D expenses in fund-raising applications; public and private investors, who constantly tend to minimize investment risks in innovative technologies; or technology scouts.

Résumé

Les startups innovantes orientées technologies mènent de nombreuses expérimentations pour recueillir suffisamment de preuves de valeur, et réduire ainsi les incertitudes avant le lancement de leurs produits et services sur le marché. Bien que les moyens des startups soient limités, ces expérimentations sont souvent aléatoires, itératives et nécessitent un investissement important en termes de temps et de ressources. Des solutions doivent ainsi leur être apportées afin de les aider à mieux planifier la maturation de leur technologie et à mieux identifier les opportunités sur le marché. C'est dans ce contexte que s'inscrit la présente recherche.

Une revue de la littérature est d'abord menée dans les domaines de l'ingénierie de la conception ainsi que du management de la technologie et de l'innovation. Cette analyse démontre que les méthodes et outils existants ne permettent pas d'établir des feuilles de route précises et quantitatives pour mener des expérimentations pertinentes. Une enquête est ensuite réalisée sur les pratiques de 60 startups innovantes dans le contexte de la Ville de Paris. Cette recherche révèle que malgré l'utilisation des méthodes d'innovation telles que Lean Startup et BMC (Business Model Canvas), les startups n'ont aucun outil pratique pour spécifier et planifier leurs expérimentations, ou pour allouer efficacement leurs ressources.

Par conséquent, cette recherche apporte trois contributions. D'abord, l'outil BMC est combiné avec la quantification des poches de valeur (opportunités) et une série d'indicateurs quantitatifs permettant d'assurer la pertinente de l'offre de valeur. Ensuite, une méthodologie dénommée DUE (*Design by Usage-based Experimentation*) est proposée afin d'examiner l'ensemble des marchés potentiels et d'identifier les principales propriétés technologiques à améliorer grâce à l'expérimentation. Une méthodologie quantitative nommée RITHM (*Roadmapping Investments in TecHnology and Market*) est par la suite proposée pour optimiser les expérimentations pour qu'elles puissent aboutir à la maturation d'une technologie pour atteindre les marchés les plus profitables. La pertinence de ces méthodologies est évaluée en les appliquant à une startup orientée technologies et par la validation d'experts. Enfin, cette recherche conclue qu'il est possible d'améliorer la spécification des feuilles de route d'expérimentations dans une startup technologique et de mieux orienter ses investissements vers des stratégies R&D plus efficaces et économiques.

Cette recherche peut contribuer à soutenir de manière significative la prise de décision de différents acteurs, comme par exemple, les entrepreneurs, qui doivent justifier des dépenses de R&D dans des dossiers de levée de fonds, ou des investisseurs publics et privés qui cherchent à minimiser les risques d'investissement dans des technologies innovantes, ou enfin des *technology scouts*.

Acknowledgements

The acknowledgement part of a PhD dissertation is probably the least-read part, similarly to the ending credits of a movie where the audience leaves the theater without noticing who was the assistant director or the scriptwriter. What I mean here is that I was the leading actor of this research work but without the help of my advisors it would have not been possible to complete this PhD. Obviously, my greetings and warm gratitude, at first place, go to my PhD supervisors at CentraleSupélec (Professor Bernard Yannou and Dr. François Cluzel) for their support, right-to-the-point comments, patience, availability, and our very productive scientific discussions. These discussions have started from the very first day of my PhD in May 2014 in the offices of the City of Paris, and continued until the last preparatory sessions before the PhD defense in a chalet in Quebec City, Canada. Warm thanks again to Bernard and François.

Speaking of Canada, working with Professor Michael Kokkolaras was a great collaboration and of course one of the highlights of this research work. Without the precious supervision of Michael, it would not have been possible to "yield" relevant optimization models. Besides, I kept very good memories of our philosophical and scientific debates at the McGill Faculty Club or at Lola Rosa restaurant in Montreal. The experience of staying at Montreal for at least 3 times (2 of them thanks to a Mitacs Globalink Award) was productive not only from the scientific point of view, but also from the life/work experience in the vibrant and innovative environment of Montreal.

The idea of living outside Paris and tearing off the cocoon of the routine life of a PhD student came to my mind from the rich experience of working in the dynamic yet open-to-the-world environment of the City of Paris. My sincere thanks go to the Department of Economic Development (*DAE: Direction de l'Attractivité et de l'Emploi*) of the City of Paris who was the main funder of this research work. Thinking of the *DAE*, the name of the first person which pups into my mind and to whom I am grateful is Frédérique Chabbert. She was my supervisor at the City of Paris for the first half of my work. Frédérique is one of the kindest, most efficient and organized person I have ever known. Besides, I would like to acknowledge the precious help of Carine Saloff-Coste, Director of the Department of Economic Development of the City of Paris; François Moreau, Chief of the *SCIRE* (*Service de Création, d'Innovation, de Recherche et d'Emploi*) of the same department; Marie Monjauze, Chief of Innovation Office of the *SCIRE*. I thank them all for their support and the follow-up after my PhD defense.

Regarding the defense, I would like to acknowledge the very relevant reports of dear reviewers of this PhD: Professor Cascini and Professor Boly. I also want to thank them

for letting my defense be an enjoyable moment of scientific discussion, and for their brilliant comments and suggestions. I would especially like to thank other jury members for their relevant questions and comments mainly Dr. Yannou-Le Bris and the dear chairman of the defense, Professor Ola Isaksson.

I also thank my lab-mates at CentraleSupélec for the stimulating discussions: Guillaume, Ouaïl, Hichame, Reza, Diya, Marija, Yann, and Flore. Many warm thanks to the members of the Industrial Engineering Lab of CentraleSupélec: Delphine, Sylvie, Corinne, Carole, and Matthieu for their appreciation and help during this research work. Moreover, I would to thank the dear Director of Research at CentraleSupélec, Olivier Gicquel, and his team, Hélène, Sylvie, Anne, and Kenny, for their kindness and support.

At the City of Paris, I thank my dear fellow office-mates: Marc-Alexandre, Nicolas, Hélène, Camille, Alexis, Pierre, Nancy, Anne, Gilda, Vincent, and also the "*CIFRE* band" Marine, Ulysse, and Dorine to whom I wish a pleasant end of PhD and a prosperous life!

From the family and friend's side, I would like to thank my precious wife and my best friend, Guilda, for supporting me emotionally, intellectually and spiritually throughout writing this thesis and, obviously, in my life in general. She has literally lived each moment of this PhD with me, and she was as excited as I was when the results were announced by the jury of the defense. A huge thank to her from the bottom of my heart for her unevaluable help and support.

Last but not the least, my father who has always supported me and who made me a great surprise of taking an overnight flight to be there for my PhD defense. Many warm thank also to my mother and my brothers, my best friends, Alex and Hamid for their spiritual support and even more.

In this long list, I am probably forgetting some dear colleagues, friends, and important persons with whom I discussed during this PhD. If your name does not appear here, it is because sometimes the heart and mind do not connect well, but the heart's memory is not erasable.

Thank you anyway!

Table of Contents

List of figures

List of tables

List of abbreviations and acronyms

BMC:	**Business Model Canvas**
BMC-RID:	**Business Model Canvas-Radical Innovation Design®**
C:	**Concept (proof of)**
DK:	**Deep Knowledge**
DSM	**Dependency and Structure Modeling of Value Buckets**
DT:	**Design Thinking**
DUE:	**Design by Usage-based Experimentation**
MML:	**Market Maturity Level**
mVB:	**Meta Value Bucket**
MVE:	**Minimum Viable Experiment**
MVEP:	**Minimum Viable Experiment Platform**
MVP:	**Minimum Viable Product**
N:	**Newness (proof of)**
P:	**Profitability (proof of)**
PPP:	**Public-Private Partnership**
R&D:	**Research and Development**
RID:	**Radical Innovation Design®**
RITHM:	**Roadmapping Investments in TecHnology and Market**
S:	**Stakeholder network (proof of)**
SVN:	**Stakeholder Value Network**
TLS:	**The Lean Startup**
TRIZ:	**"Theory of the resolution of invention-related tasks"**
TRL:	**Technology Readiness Level**
U:	**Usefulness (proof of)**
UrCI:	**Urban-Centered Innovation**
VB:	**Value Bucket**
VPD:	**Value Proposition Design**
EOSA:	**Environment, Operator, Strategy, and Artifact of a test**

Glossary

This glossary includes the main terms used in this dissertation. For each entry, a brief definition is provided. The asterisk (*) indicates the new terms proposed by this research.

Business Model Canvas-Radical Innovation Design® (BMC-RID) method*: hybridization of the BMC and the RID methodology. It enables a more rational and wiser use of the BMC through an organized mechanism and a set of guidelines.

Business Model Canvas: qualitative and informal tool for structuring business models. It "*describes the rationale of how an organization creates, delivers, and captures value*" (Osterwalder and Pigneur, 2010).

Current maturity matrix*: refers to the matrix that links the current development level of a property of a technology to a promising market. The value in each cell of this matrix is measured with a 0 to 5 intensity scale which is therefore different from the TRL scale (from 0 to 9).

Customer Development: four-step process invented by Steve Blank to reduce the risk and uncertainty in entrepreneurship by continuously testing the hypotheses underlying a business model with customers and stakeholders (see (Blank, 2013)).

Deep Knowledge: several categories of knowledge necessary to an innovation, that must be investigated from the front end of innovation (Bekhradi et al., 2017). These categories can include frequent usage scenarios, important users' problems, causes and consequences of these problems, as well as more or less effective solutions (and technologies) that exist to deal with these problems.

Dependency and Structure Modeling of meta Value Buckets (DSM-mVB)*: algorithm which links promising markets (characterized by value buckets) to key properties of a technology in a set of matrices that compute meta value buckets (see meta value buckets).

Dependency and Structure Modeling of Value Buckets (DSM-VB): algorithm which links users' problems, usage scenarios, and existing solutions in a set of matrices that compute value buckets (see value buckets).

Design by Usage-based Experimentation (DUE)*: structured process along with a set of tools that enable screening a set of usages of a technology to identify the main technology properties to be improved through experiments for its promising markets.

Design Thinking: "*human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success*" (Brown, 2009).

Double Diamond: simple visual map of the design process as well as a set of underlying concepts divided into four distinct phases: Discover, Define, Develop and Deliver (see (DesignCouncil, 2005)).

DUE test card*: visual template inspired by the Test Card as proposed by (Osterwalder et al., 2015). A DUE test card is structuring tool for experimentation and it contains three key information: meta value bucket, hypotheses of experiment, actions to be conducted in experiments.

Experiment (noun): procedure or a set of actions to validate or invalidate a hypothesis. Startups conduct experiments to not only explore the effects of manipulating a variable related to a product or service, but also to verify their business assumptions. Even though "experiment" is different than "test" (i.e., assessment of the presence, quality, or genuineness of something), tests and experiments have more similarities than differences (see (Kass, 2008)). Therefore, these terms can be used interchangeably (see also testing).

Experimentation Libraries*: first deliverable of the DUE process which is an important knowledge base that keep the trace of an important part of the company's R&D activities in terms of testing activities, their cost, time, and conditions.

Experimentation: process of creating knowledge which leads to the development and improvement of products, processes, systems, and organizations (see testing activity).

Innovation advisor of a startup: innovation expert or a Subject Matter Expert (SME) supervising the business and technology maturation of a startup. Most often, s/he is specialized in business, technology, and legal aspect. These experts are, in general: members of the advisory board of the startup (if it has any), business development coaches at innovation incubators (if the startup is incubated), and legal advisors (such as lawyers).

Innovation problem: relevant problem of users or customers (or potential value beneficiaries of an innovation in general).

Lean Startup: "*set of practices for helping entrepreneurs increase their odds of building a successful startup*" (Ries, 2011).

Market maturity gap*: see meta value bucket.

Market Maturity Level*: scale from 1 to 7 which is inspired by the TRL. This scale is only used in the framework of semi-directive interviews conducted with 60 innovative startups.

Market-Technology Libraries*: first deliverable of the DUE process which is an important knowledge base that keep the trace of an important part of the company's R&D activities in terms of identifying markets and improving the technology.

Meta value bucket (mVB)*: combination of a property of the technology and a promising market (characterized by a value bucket). It reflects the market maturity gap to be targeted through experiments.

Minimum Viable Experiment (MVE)*: Pareto-optimal testing activity that enables reaching a promising market with minimized investments in time and cash.

Minimum Viable Experiment Platform (MVEP)*: Pareto-optimal sequence of combined testing activities that enables reaching a promising market with minimized investments in time and cash.

Minimum Viable Product (MVP): version of a product with its key features to satisfy early adopters (customers), and to provide feedback for future product development.

Promising market*: market where the technology has a high a likelihood of value creation, because there are important value buckets.

Property of a technology*: characteristic or ability of a technology. As opposed to existing approaches that merely focus on the technical functions or technology affordances, the emphasis is put on the broader concept of usage and the potential of the technology to satisfy usage scenarios.

Prototyping: practice of building physical and/or virtual models to be tested. A prototype can be of high or low fidelity (i.e., approximating the features of the final product and service).

Radical Innovation Design® (RID): structured usage-driven methodology to explore the front end of innovation compatible with the need seeker strategy. RID supports the systematic modeling of classes of usage situations, problems and existing solutions to generate value buckets as the target of an innovation project, before designing a solution and its business models (Yannou et al., 2013; Lamé et al., 2017; Yannou et al., 2018).

Required maturity matrix*: matrix that links the maturity level of a property of a technology to a promising market. The required maturity level of a technology represents the threshold from which a technology is considered as "ready" to meet a given market. The value in each cell of this matrix is measured with a 0 to 5 intensity scale which is therefore different from the TRL scale (from 0 to 9).

Research and Development (R&D) activity: activity undertaken by companies or other organizations in developing new products and/or services, or improving the existing ones. These activities contribute to "*increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge*" (OECD, 2015). In a very high-level, R&D activities include basic research, applied research, and experimental development.

Roadmapping Investments in TecHnology and Markets (RITHM)*: methodology that aims at optimizing the set of experiments so that they result in the definition of a technology with properties that are mature enough to meet the most profitable markets.

Stakeholder network (proof of)*: An innovativeness proof which is added to the set of UNPC innovativeness indicators of the RID methodology. This proof measures the degree to which: the whole value network is relevant; partnership decisions are coherent with the global strategy of the company, and clear networking actions, such as lobbying and building partnerships, are considered or has been initiated.

Stakeholder Value Network (SVN): "*a multi-relational network consisting of a focal organization, the focal organization's stakeholders, and the tangible and intangible value exchanges between the focal organization and its stakeholders, as well as between the stakeholders themselves*" (Feng and Crawley, 2009).

Stakeholder: "*any group or individual who can affect or is affected by the achievement of the organization's objectives*" (Freeman, 2010).

Startup (or start-up) company: "*human institution designed to deliver a new product or service under conditions of extreme uncertainty*" (Ries, 2011). The term "startup" is preferred to Small and Medium Businesses (SMB), because the latter does not reflect the same configuration and challenges of a startup. Indeed, the latter is founded, in most cases, by individual founders or entrepreneurs to search for a viable and scalable business model meet a marketplace need or problem.

Technological innovation: one of the central enablers of innovation. It reflects both the business considerations and technological functions of an innovative products or services.

Technology acquisition: acquisition of technology and knowledge involves the purchase of external knowledge and technology without active cooperation with the source (or target firm) (OECD, 1997). Technology acquisitions can include the hiring of employees, the access to a market, securing assets, accessing a know-how, patents, licenses or a customer portfolio.

Technology forecasting: discipline of the technology management that provides some support by using forecasting principles to the dynamic behavior of technology and innovation. This discipline is usually practiced by scholars and by specialist consultants.

Technology maturation: series of activities required to bring an immature technology to a desired maturity level.

Technology Readiness Level (TRL): measurement system used to assess the maturity level of a technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels with TRL 1 as the lowest and TRL 9 as the highest.

Technology Roadmapping (TRM): "*technology management and planning, especially for exploring and communicating the dynamic linkages between technological resources, organizational objectives and the changing environment*" (Phaal et al., 2004).

Technology scout: external consultant or an employee of an acquirer company (i.e., a company that acquires a technology from a target organization) (Rohrbeck, 2010). The

mission of technology scouts consists in not only exploring technologies, but also in evaluating, matching and securing successful execution of acquisitions.

Technology-based startup: see “Technology-oriented innovative startups”.

Technology-oriented innovative startup*: startup firm that has an innovative core (or platform) technology to make mature and to launch on the market.

Technology: “*application of scientific knowledge for practical purposes, especially in industry*”. In most cases, this definition extends beyond industrial applications to encompass marketing and investment implications.

Test (noun): “*deliberate action or experiment to find out how well something works*” and whether the hypotheses must be accepted or rejected.

Test Card: strategic testing tool proposed by Osterwalder et al. to “*design and structure research and experiments*” (Osterwalder et al., 2015).

Testing activity: key R&D activity of technology-oriented innovative startups. It consists in an operation or procedure carried out under controlled conditions to generate new knowledge in order to improve the maturity of a product or service. This operation or procedure has a financial cost and takes time (see experimentation).

TRIZ: Theory of Inventive Problem Solving which is an efficient problem-solving approach in product development (see (Altshuller, 1984)). TRIZ includes a set of tools, a knowledge base, and model-based technology for generating innovative solutions for problem solving.

UNPC: set of innovativeness proofs standing for Usefulness, Newness, Profitability, and Concept (proof of). This set of indicators is used to evaluate and select innovative products and services (Yannou, Farel, et al., 2016)

UNPCS*: set of innovativeness proofs standing for Usefulness, Newness, Profitability, Concept (proof of), and Stakeholder Network. This set of indicators is proposed as an extension of the UNPC proofs in the context of innovation ecosystem and mainly innovative startups.

Urban-Centered Innovation (UrCI)*: emerging category of innovative products and services developed by city-based startups. Their aim is to create high social-economic value by responding to end-users’ problems and jobs-to-be-done.

Usage *(usage situation, usage scenario, and usage context)*: broad concept that does not have a single definition. A usage scenario is an archetypal story lived by a representative group of users, where one may identify an important problem, whereas a usage context enables capturing personal and environmental factors and lifestyles (He et al., 2012).

Value bucket (VB): combination of a problem and usage scenario. A VB represents important problems occurring in frequent usage scenarios for which the existing solutions are generally neither efficient nor useful (Yannou, Cluzel, et al., 2016; Lamé et al., 2017).

Value offer (or value proposition): a promise of value to be delivered to customers. This is indeed the innovative products and services designed by startup companies.

Value Proposition Design (VPD): process and a set of hands-on visual tools proposed by Osterwalder et al. (Osterwalder et al., 2015). The VPD approach serves to design, test, build, and manage value propositions over their entire lifecycle.

References of the glossary

Altshuller, G. S. (1984). *Creativity as an exact science: the theory of the solution of inventive problems*. Amsterdam, Netherlands: Gordon and Breach. 0677212305.

Bekhradi, A., Yannou, B., Cluzel, F., and Vallette, T. (2017). *Categorizing user pains, usage situations and existing solutions in front end of innovation: The case of smart lighting project*. Paper presented at the The 21st International Conference on Engineering Design, ICED17, Vancouver, British Columbia, Canada. August 21-25.

Blank, S. (2013). *The four steps to the epiphany: successful strategies for products that win*. New Jersey, United States: BookBaby. 0989200523.

Brown, T. (2009). *Change by design: How Design Thinking Transforms Organizations and Inspires Innovation*. New York, United States: HarperBusiness.

DesignCouncil. (2005). The 'double diamond' design process model. *Design Council*. Retrieved from: https://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond. Access date: July 2018.

Feng, W., and Crawley, E. (2009). Stakeholder value network analysis for large oil and gas projects. *Massachusetts Institute of Technology, Engineering Systems*.

Freeman, R. E. (2010). *Strategic Management: A Stakeholder Approach*. Cambridge, United Kingdom: Cambridge University Press. 9780521151740.

He, L., Chen, W., Hoyle, C., and Yannou, B. (2012). Choice Modeling for Usage Context-Based Design. *Journal of Mechanical Design, 134*(3), 031007-031007-031011. doi:10.1115/1.4005860

Kass, R. A. (2008). Tests and Experiments: Similarities and Differences. *International Test and Evaluation Association, 29*, 294–300.

Lamé, G., Yannou, B., and Cluzel, F. (2017). Usage-driven problem design for radical innovation in healthcare. *BMJ Innovations, 4*(1), 15-23.

OECD. (1997). *The measurement of scientific and technological activities: Proposed guidelines for collecting and interpreting technological innovation data: Oslo manual*: OECD.

OECD. (2015). *Frascati manual 2015: guidelines for collecting and reporting data on research and experimental development*: OECD Publishing. 9264238808.

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey, United States: Wiley. 9780470901038.

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., and Papadakos, T. (2015). *Value Proposition Design: How to Create Products and Services Customers Want*. New Jersey, United States: Wiley. 9781118968055.

Phaal, R., Farrukh, C. J., and Probert, D. R. (2004). Technology roadmapping—a planning framework for evolution and revolution. *Technological Forecasting and Social Change, 71*(1-2), 5-26.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

Rohrbeck, R. (2010). Harnessing a network of experts for competitive advantage: technology scouting in the ICT industry. *R&D Management, 40*(2), 169-180.

Yannou, B., Cluzel, F., and Farel, R. (2016). Capturing the relevant problems leading to pain and usage driven innovations: the DSM Value Bucket algorithm. *Concurrent Engineering: Research and Applications*, 1 - 16. doi:10.1177/1063293x16666311

Yannou, B., Farel, R., Cluzel, F., Bekhradi, A., and Zimmer, B. (2016). The UNPC innovativeness set of indicators for idea or project selection and maturation in healthcare. *International Journal of Design Creativity and Innovation, 5*(3-4), 205-221. doi:10.1080/21650349.2016.1161562

Yannou, B., Jankovic, M., Leroy, Y., and Kremer, G. E. O. (2013). Observations from radical innovation projects considering the company context. *Journal of Mechanical Design, 135*(2), 021005.

Yannou, B., Lamé, G., and Cluzel, F. (2018). *Adapting the FBS model of designing for usage-driven innovation processes.* Paper presented at the IDETC/CIE 2018: International Design Engineering Technical Conferences/CIE: Computers and Information in Engineering, Montreal, Canada. August 2018.

List of personal publications

The following list includes research contributions directly and indirectly related to this dissertation and written during this PhD research:

Journal papers

- Bekhradi, A., Yannou, B., Farel, R., Zimmer, B., and Chandra, J. (2015). Usefulness simulation of design concepts. *Journal of Mechanical Design*, *137*(7):071414. doi:10.1115/1.4030180.

- Yannou, B., Farel, R., Cluzel, F., Bekhradi, A., and Zimmer, B. (2016). The UNPC innovativeness set of indicators for idea or project selection and maturation in healthcare. *International Journal of Design Creativity and Innovation*, *5*(3-4), 205-221. doi:10.1080/21650349.2016.1161562

Submitted papers

- Bekhradi, A., Yannou, B., Cluzel, F., and Chabbert, F. (2018). Fostering Urban-Centered Innovation through real-world experiments of innovative products and services. *Submitted to the Journal of Urban Technology*.

- Bekhradi, A., Yannou, B., and Cluzel, F. (2018). Do innovative startups rigorously design and test a product or service?. *Submitted to Journal of Small Business Management*.

- Bekhradi, A, Yannou, B., and Cluzel, F. (2018). Capturing relevant innovation problems for a more rational use of the Business Model Canvas (BMC), *Submitted to Journal of Business Research*.

- Bekhradi, A, Yannou, B., and Cluzel, F. (2018). Identifying relevant market gaps through experimentation: proposition of the Design by Usage-based Experimentation (DUE) methodology, *Submitted to Research in Engineering Design*.

- Bekhradi, A, Yannou, B., and Cluzel, F. (2018). Optimizing R&D activities for technology maturation: proposition of the RITHM (Roadmapping Investments in TecHnology and Markets) methodology, *Submitted to International Entrepreneurship and Management Journal*.

Conference papers

- Bekhradi, A., Yannou, B., Cluzel, F., and Kokkolaras, M. (2018). Decision support for R&D activities of innovative technologies. IDETC/CIE 2018: International Design Engineering Technical Conferences/CIE: Computers and Information in Engineering, Quebec, Canada, August 2018.

- Bekhradi, A., Yannou, B., Cluzel, F., and Vallette, T. (2017). Categorizing user pains, usage situations and existing solutions in front end of innovation: The case of smart lighting project. Paper presented at The 21st International Conference on Engineering Design, ICED17, Vancouver, British Columbia, Canada. August 2017.

- Bekhradi, A., Yannou, B., and Cluzel, F. (2016). Importance of problem setting before developing a business model canvas. 14th International Design Conference - DESIGN 2016, Dubrovnik, Croatia. May 2016.

- Bekhradi, A., Yannou, B., Cluzel, F., and Chabbert, F. (2016). Fostering urban-centered innovation. 14th International Design Conference - DESIGN 2016, Dubrovnik, Croatia. May 2016.

- Bekhradi, A., Yannou, B., Cluzel, F., Chabbert, F., and Farel, R. (2015). In Vivo In Situ Experimentation Projects by Innovative Cleantech Start-Ups in Paris. ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Boston, Massachusetts, United States. August 2015. http://dx.doi.org/10.1115/DETC2015-47631

Other publications

- Rostama, G., Bekhradi, A., and Yannou, B. (2017). From privacy by design to design for privacy. International Conference on Engineering Design (ICED), Vancouver, Canada. August 2017.

- Bekhradi, A., and Chabbert, F. (2015), Expérimentation des innovations sur les territoires publics, *Déployer l'innovation : Méthodes, outils, pilotage et cas d'étude,* Techniques de l'Ingénieur, Paris, France.

General introduction

Technology maturation in the context of innovative startups

"*All firms have technologies*", stated Clayton M. Christensen (Christensen, 2013). The Oxford Dictionary of English defines the concept of technology as the "*application of scientific knowledge for practical purposes, especially in industry*". However, it is also acknowledged that this definition extends beyond its industrial applications to encompass marketing and investment implications in the context of startup companies that design, test and deliver a technological innovation. Such startups represent more than 70% of all startups (Wu and Atkinson, 2017).

An innovative startup or entrepreneurial venture is defined as a human organization that designs, tests, and delivers products and services in the "*conditions of extreme uncertainty*" (Ries, 2011). The process of starting up a business encompasses a complex and challenging task, notably in its early stages, where effort and investment focus on transforming the innovative idea into one or several marketable products, while at the same time raising funds and conducting testing activities (or experiments). Technology-based startups[1] (i.e., those that aim at transforming inventions and high-tech concepts into viable businesses) may face even greater challenges as they operate in an ever-changing environment where large investments are required to support technology development in a short timeframe. In this dynamic setting, the effectiveness of the technology development roadmaps of a startup has considerable impact on the likelihood of its market success.

The concept of "market" can be regarded from different perspectives such as sociology, economic history, and marketing. The basic economic definition of market denotes the mechanism whereby demand (composed of customers), and supply (made up of suppliers) confront. From the perspective of management of innovation, (Cantamessa and Montagna, 2016) outline a set of criteria to define a market, including geography, product similarity, switching behavior, and demographic criteria. Given the multiple definitions and criteria, it is not trivial to circumscribe a "relevant market". In this thesis, the challenge is to elicit a relevant market through the exploration of useful problems of people from early innovation phases that are called the *front end of innovation*.

[1] The term "startup" is commonly associated with technology. However, a startup does not have to be tech-based by nature. A startup is any early-start organization that aspires to innovate, solve real problems, and bring value to improve the life of modern society, regardless of whether technology is used.

These challenges are covered in the recent literature of innovation management, which includes a set of principles dealing with the R&D activities (mainly composed of basic research, applied research, and experimental development), with the design process of a product-service, and also with the mechanisms of entrepreneurial business development (Cantamessa and Montagna, 2016). Therefore, the principles of innovation management and engineering design are at the core of this thesis. We focus on managing and engineering technology roadmaps of companies and in particular those of startups.

Research perimeter

The studied perimeter in this thesis is those of innovative startups that evolve in larger urban areas. From the early 2000s, European and American cities have attracted smarter and more entrepreneurial people by dedicating zones for the purpose of clustering entrepreneurs (Katz and Wagner, 2014). Accordingly, the urban area influences the attitudes and decision-making of today's entrepreneurs. In turn, startups' success influences local growth and job creation (Glaeser et al., 2010). This fact has created, among other consequences, a race between metropolitan cities to become the most attractive city of innovation and entrepreneurship. Paris, which is the city we have chosen to focus on in this thesis, is often listed as one of the top-five most innovative cities in the world (PWC, 2016).

Challenge

Cities adopt new local policies and marshal public funds as well as other resources to support them. In this context, the municipality of Paris has dedicated financial resources to seed-fund these startups with a large majority of technology-based startups. For instance, the City of Paris has co-created the *Paris Innovation Amorçage* fund with BPI France (*Banque Publique d'Investissement*). The City offers an important number of infrastructures dedicated to startups (e.g., innovative incubators, co-working places and fablabs (Alba et al., 2016)).

But more importantly, the City of Paris launched in 2009 an experimentation policy to help startups run tests in real-life situations. These tests aim at helping startups to reduce uncertainties and improve their value offer before either the commercialization phase or application to a public procurement process. To structure the activity of experimentation, the City has created an ad hoc entity, called Urban Lab (UrbanLab, 2017). Urban Lab organizes calls for experimentation and facilitates the access of startups to public places to run their tests. Since 2009, almost 50 experimentation projects have been conducted per year on average, and each year the City grants them considerable financial and human resources. However, as the time and resources of

public organizations and startups are limited, the cost-effectiveness of these experiments is essential.

Problem statement

Conducting cost-effective experiments allows money and time to be saved, and ultimately increases the startups' likelihood of success. This success matters to the local and national economy, since startups are one of the building blocks of growth and job creation. However, it is commonly known that most startups fail (see for instance (Ries, 2011)).

The rate of startup creation is surprisingly rapid: during the five minutes taken to read this introduction, almost 1000 startups have emerged around the globe (Mason, 2018). But the question is how many of them will survive and positively contribute to the local and national economy? In general, the fatality rate of startups is high, even though there are very few reliable statistics regarding this *failure* rate. For instance, most conventional business publications claim that 90% of startups fail in the first three or five years (see for instance (Patel, 2015; Peach, 2018)). The lack of reliable statistics may be due to the ambiguous definitions of terms such as "startup", "failure", "survival" or "failure reason". In France, the report of the national institute for statistical and economic studies (INSEE) in 2016 shows that 40% of new French companies do not survive longer than 5 years (Béziau, 2017). Although the 40% refers to companies including startups, the failure rate of French startups is high. This is problematic in a country where more than two thirds of the funds dedicated to innovative startups come from public resources (Ezratty, 2018).

Although several reasons help explain startup failures, mostly related to an entrepreneur's personality and skills, there may also be underlying causes of failure at the value offer and business model levels. For instance, a poor understanding of the "*need on the market*" is considered as the first cause of failure among startups (CB-Insights, 2014). The existence or non-existence of such important need/problem on the market must be revealed through from early development stages and also from well-conducted experiments. However, in practice, experiments remain loop-based trials and errors following the *excuse* of 'market and customers are uncertain' and, above all, 'a startup can (or must) pivot'. Consequently, the waste due to the lack of structured and planned experiments can be substantial both for the startup as well as for its investors and supporters (in our case, a municipality)[2].

[2] On a panel of 60 startups interviewed during this research project, €2.5 M were spent by the City of Paris on experimentation projects. However, 27% of these innovative startups failed and drained more than 20% of these €2.5 M allocated to experimentation projects (Bekhradi et al., 2018).

Even though popular entrepreneurship methods and tools enable technology-oriented innovative startups to conduct more systematic experiments (cf. Lean Startup (Ries, 2011), Design Thinking (Brown, 2009), Value Proposition Design (Osterwalder et al., 2015)), they seem to fail at systematically planning experiments and supporting R&D investment decisions. As experimentation reflects the major R&D activity of this category of startups (Kerr et al., 2014; Blank, 2013; Ries, 2011; Moogk, 2012), its rational and cost-effectiveness matter to the innovation ecosystem. There is therefore a clear need to identify and plan cost-effective experiments that enable such startups to efficiently improve their technology for the most promising markets. We have therefore chosen to focus in this thesis on the topic of roadmapping experiments in technology-oriented innovative startups.

Research positioning and research flow

This PhD research was granted by a CIFRE[3] agreement between the City of Paris and Industrial Engineering Research Department (*Laboratoire Génie Industriel*, LGI) at CentraleSupélec.

The City of Paris and the Parisian Urban Lab manage and monitor several experimentation projects by granting access for startups to public places and resources. Our research work has therefore been carried out in close collaboration with the officials of the City and Urban Lab, as well as with innovative startups that experiment in the Paris urban area.

In this context, the first steps of our research consisted not only in reviewing the related interdisciplinary literature, but also in observing industrial and organizational practices, both at the scale of the City and at the scale of startups. A primary observation was carried out through the exploration of 132 real-world experimentation projects of innovative startups, and has led us to conclude that public organizations such as municipalities can contribute to the success of startups, by better selecting and evaluating their experimentation projects. To further explore this observation, we subsequently focused our analysis at the scale of startups, by conducting semi-directive interviews of 60 innovative startups. A long-term observation over this panel of startups showed that 27% of them failed because their value proposition did not deliver real and viable value to customers. A deep analysis of this failure revealed that: startups lacked important knowledge about customers' problems, pains, and jobs-to-be-done (Christensen et al., 2016), and the experiments conducted did not systematically enable them to gain more in-depth knowledge about their customers.

[3] *CIFRE*: *Convention industrielle de formation par la recherche*.

The lack of use or misuse of existing design and testing methods and tools explained this important lack of knowledge.

Therefore, the focus of the rest of the thesis remains on the startup level, and three research questions are formulated. New models for supporting design and testing activities of startups are proposed for testing and validation. To carry out the test and validation steps of this research, we directly worked with technology-oriented innovative startups to collect data and verify and validate the models developed. In addition, at the end of the period of this PhD research a partnership with the Systems Optimization Lab (SOL) of McGill University enabled us to reach two main objectives: (i) to develop and test the optimization algorithms of the last chapter of this dissertation; and (ii) to become acquainted with the innovation ecosystem in Montreal. The latter helped us to study another large urban area other than Paris, which invests in innovation and supports innovative startups.

Consistent with the principles of Action Research approach (i.e., observation of design practices, identification of scientific issues, new model proposition, and deployment and validation in the industrial context (cf. (Yannou and Petiot, 2011)), we have defined the research flow of this thesis. The overall research flow of this thesis is depicted in Figure 1. From the initial research problem, the first two steps consist in conducting diagnosis and interviewing startups (steps 01 and 02). Based on the conclusions drawn from the first and second steps, three research questions are identified in step 03. We respond to these research questions through models for supporting design and testing activities of startups that are developed in step 04. These models are then tested and validated in step 05.

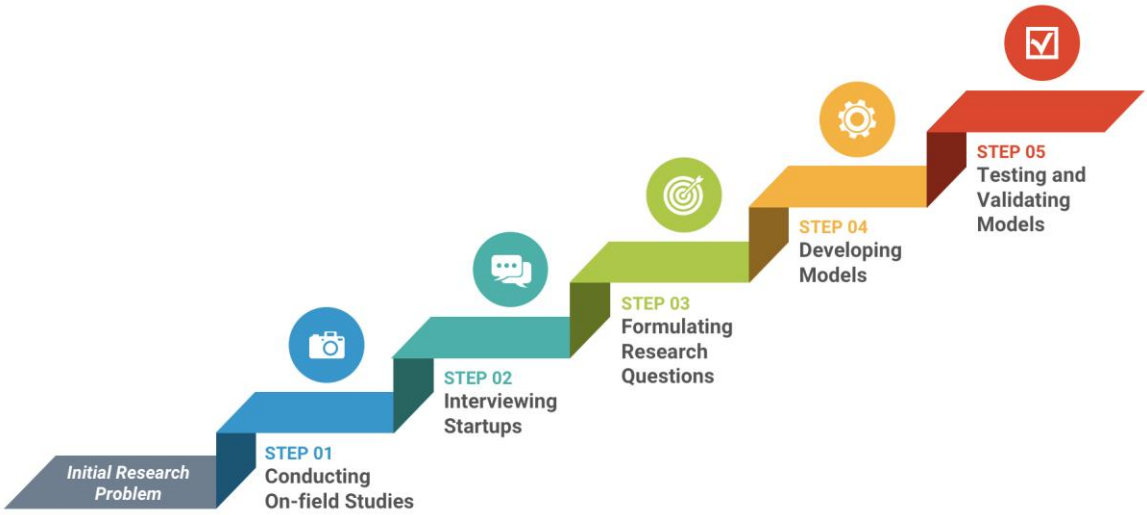


Figure 1. Overview of major research steps

Research questions

The observations in steps 01 and 02 reveal that, despite existence the use of the most popular innovation methods such as Business Model Canvas (BMC) (Osterwalder and Pigneur, 2010) and Lean Startup (Ries, 2011), startups have no practical tools for specifying and planning experiments, nor for efficiently using public funds. Based on these observations, three research questions are formulated as below:

(1) How to ensure that the startup's value offer, described in a Business Model Canvas (BMC), is significant and effective before the completion of the BMC and the launch of experiments?

The BMC is the most popular tool used among innovative startups according to the results of our observations. However, although it is generally used by technology-based startups to frame their experiments, it doesn't necessarily provide quantitative proofs confirming that the targeted value offer leads to significant value creation. We therefore suggest a set of indicators and processes to improve the use of the BMC.

(2) What are the most promising markets and the technology properties that a technology-oriented innovative startup should target through experiments, with limited resources and time?

The existing methods and tools in innovation and technology management as well as in engineering design fail to provide a relevant technique to screen the most promising

markets (those containing significant value creation opportunities) and the main technology properties that need to be improved and controlled. We therefore see how the identified markets and technology properties can be linked to identify the weaknesses of the technology to be improved through experimentation.

(3) How to identify the most cost-effective R&D activities and their short-term planning that will enable a technology-oriented innovative startup to improve the maturity of its technology and successfully meet the promising markets?

In the context of a technology-based startup with limited time and resources, R&D activities, and mostly experiments, are more often random and loop-based. In addition, there is no practical tool to specify and plan cost-effective activities. Therefore, investments of a startup remain rather unplanned and based on the intuition or sporadic market research of entrepreneurs. We therefore suggest a tool and an optimization process to plan more cost-effective R&D activities with a particular focus on testing activities.

Expected contributions to the academic literature and industrial practices

The findings of this thesis will benefit urban decision-makers, entrepreneurial stakeholders, and researchers in several ways.

On a macro-level, urban decision-makers who allocate funding to innovative startups may find the first investigation results of this thesis particularly useful. These results (delineated in Chapter 1) provide the first source of insight on how to select and evaluate real-world experimentation projects following a set of quantitative indicators adapted to Urban-Centered Innovations (UrCI).

Furthermore, the results of a diagnostic on underlying reasons for startup failure can be insightful for innovation practitioners. The proposed methodologies in this thesis can be useful for startups and their mentors, as they help make sound investment decisions and conduct cost-effective experiments. In addition, these methodologies may provide relevant proofs to investors regarding the market and technology targets of a startup in a fundraising process.

Academics in the fields of product development and entrepreneurship may also benefit from the results of this research, in terms of articulating the technology and market-related experiments in the context of startups. The proposed methodologies are provided with technical documentation that can be used for educational purposes.

Besides, we hope that our findings will further encourage academic discussion about the use of rigorous methods and tools in entrepreneurial and intrapreneurial contexts.

Dissertation structure

This dissertation is structured as a series of five scientific papers, each representing a chapter. Each chapter follows a classical structure of a scientific paper, i.e., abstract, introduction, literature review, research method, results, discussion, conclusion, and finishes with references and appendices. Therefore, this dissertation does not contain separate chapters addressing the general literature review and the research method.

The five papers are organized into two parts. The first part is called **Field investigations** and includes two chapters covering the first and second part of our research flow (see Figure 1).

Chapter 1 introduces a new concept coined as Urban-Centered Innovation (UrCI) which consists in innovations that, in addition to being user-centered, have other differentiating characteristics related to the urban area and its stakeholders. We point out that experimentation is of utmost importance to UrCI. We explore the case of the City of Paris through the analysis of the applications of 132 experimentation projects.

Chapter 2 investigates the design and testing practices of 60 innovative startups that have participated in the experimentation projects of the City of Paris. This investigation reveals that despite of the existence of the most popular innovation methods, they fail at systematically planning experiments and supporting R&D investment decisions of innovative startups.

In line with the third step of our research flow (see Figure 1), the first part ends with the formulation of the three research questions based on the above-mentioned field investigations.

The second part is called **Contributions** and deals with the three identified research questions. These three questions are tackled in the three remaining chapters of this dissertation. The answers to these questions entail the fourth and fifth steps of our research flow as depicted in Figure 1. Each chapter proposes a new methodology to structure and improve the design and testing practices of technology-oriented innovative startups.

Chapter 3 presents a new way of using the popular Business Model Canvas (BMC) by providing quantitative indicators that allow startups and innovation practitioners to

verify the relevance of the value offer before developing other parts of a business model and before launching experiments.

Chapter 4 outlines a new methodology, called Design by Usage-based Experimentation (DUE), that enables startups to screen the whole set of profitable markets and to identify the main technology properties to be improved through experiments.

Chapter 5 proposes a new methodology, called RITHM (Roadmapping Investments in TecHnology and Market), which aims at optimizing the set of experiments so that they result in the definition of a technology with properties that are mature enough to meet the most profitable markets.

The third part of this dissertation consists in **General discussions** on the results obtained and their overall consistency, as well as on the implications and adaptation of the proposed methodologies in other contexts.

References of the general introduction

Alba, D., Villot, A.-M., Ribeiro, M., Roger, S., Dosseur, L., and Delapierre, J.-B. (2016). *L'innovation à Paris et dans la Métropole du Grand Paris : Données sur les startups, les lieux, les méthodes*. Retrieved from Paris.Paris:

Bekhradi, A., Yannou, B., and Cluzel, F. (2018). Do innovative startups rigorously design and test a product or service? *Submitted to Journal of Small Business Management*.

Béziau, J. (2017, 22/03/2017). Enterprises created in 2010: More sustainable than those created in 2006, and affected by the crisis. *INSEE Première.* Retrieved from: https://www.insee.fr/en/statistiques/2856501. Access date: July 2018.

Blank, S. (2013). *The four steps to the epiphany: successful strategies for products that win*. New Jersey, United States: BookBaby. 0989200523.

Brown, T. (2009). *Change by design: How Design Thinking Transforms Organizations and Inspires Innovation*. New York, United States: HarperBusiness.

Cantamessa, M., and Montagna, F. (2016). *Management of innovation and product development*. London, United Kingdom: Springer. 1447167228.

CB-Insights. (2014). The top 20 reasons startups fail. *CB Insights*. Retrieved from: https://www.cbinsights.com/research/startup-failure-reasons-top/. Access date: July 2018.

Christensen, C. (2013). *The innovator's dilemma: when new technologies cause great firms to fail*. Massachusetts, United States: Harvard Business Review Press. 9781633691780.

Christensen, C., Hall, T., Dillon, K., and Duncan, D. S. (2016). Competing against luck. *HBX Connext. Harvard Business School, Boston, 6*.

Ezratty, O. (2018, April 2018). Guide des Startups en France. Retrieved from: http://www.oezratty.net/wordpress/wp-content/themes/Ezratty5/fd.php?file=/Files/Publications/Guide%20des%20Startups%20en%20France%20Olivier%20Ezratty%20Apr2018.pdf. Access date: July 2018.

Glaeser, E. L., Rosenthal, S. S., and Strange, W. C. (2010). Urban economics and entrepreneurship. *Journal of Urban Economics, 67*(1), 1-14.

Katz, B., and Wagner, J. (2014). The Rise of Innovation Districts: A New Geography of Innovation in America. *Brookings Institution.* Retrieved from: https://www.brookings.edu/wp-content/uploads/2016/07/InnovationDistricts1.pdf. Access date: July 2018.

Kerr, W. R., Nanda, R., and Rhodes-Kropf, M. (2014). Entrepreneurship as experimentation. *Journal of Economic Perspectives, 28*(3), 25-48.

Mason, M.-K. (2018). Worldwide Business Start-Ups. Retrieved from: http://www.moyak.com/papers/business-startups-entrepreneurs.html. Access date: July 2018.

Moogk, D. R. (2012). Minimum viable product and the importance of experimentation in technology startups. *Technology Innovation Management Review, 2*(3).

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey, United States: Wiley. 9780470901038.

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., and Papadakos, T. (2015). *Value Proposition Design: How to Create Products and Services Customers Want*. New Jersey, United States: Wiley. 9781118968055.

Patel, N. (2015). 90% Of Startups Fail: Here's What You Need To Know About The 10%. *Forbes. com.* Retrieved from: https://www.forbes.com/sites/neilpatel/2015/01/16/90-of-startups-will-fail-heres-what-you-need-to-know-about-the-10/ - 4da901f26679. Access date: July 2018.

Peach, C. (2018). 90% of Startups Fail Within 3 Years — Here's How I'm Staying Afloat. Retrieved from: https://www.gobankingrates.com/making-money/entrepreneur/90-percent-startups-fail-3-years/. Access date: July 2018.

PWC. (2016). Cities of Opportunity 7. Retrieved from: https://www.pwccn.com/en/cities-of-opportunity/cities-of-opportunity-7.pdf. Access date: July 2018.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

UrbanLab. (2017). Urban Lab: Tous nos projets. Retrieved from: https://urbanlab.parisandco.paris/. Access date: July 2018.

Wu, J. J., and Atkinson, R. (2017, November 2017). How Technology-Based Start-Ups Support US Economic Growth. Retrieved from: https:// http://www2.itif.org/2017-technology-based-start-ups.pdf. Access date: July 2018.

Yannou, B., and Petiot, J.-F. (2011). A View of Design (and JMD): The French Perspective. *Journal of Mechanical Design, 133*(5), 050301-050301-050302. doi:10.1115/1.4004032

PART I. FIELD INVESTIGATIONS

The studied perimeter of this research involves innovative startups that evolve in larger urban areas. To cover this perimeter, the first part of this dissertation is dedicated to investigating innovation both at the macro scale of the urban area (chapter 1) and at the micro-scale of startup's value offer (chapter 2).

More specifically, chapter 1 concentrates on innovation from the perspective of the urban area and its stakeholders. It also introduces and details the concept of Urban-Centered Innovation (UrCI).

After having investigated the UrCI, the focus of this thesis starts from chapter 2 to shift from the urban area to innovative startups and their value offer. This chapter explores the practices of these startups from design and testing perspectives.

Chapter 1. Paper #1: Fostering urban-centered innovation through real-world experiments

This paper is submitted to the Journal of Urban Technology in November 2018, under the following reference:

- Bekhradi, A., Yannou, B., Cluzel, F., and Chabbert, F. (2018). Fostering Urban-Centered Innovation through real-world experiments of innovative products and services. *Submitted to the Journal of Urban Technology*.

A conference paper as well as a technical document (in French) provide the basis of this paper:

- Bekhradi, A., Yannou, B., Cluzel, F., and Chabbert, F. (2016). Fostering urban-centered innovation. 14th International Design Conference - DESIGN 2016, Dubrovnik, Croatia. May 2016.

- Bekhradi, A., and Chabbert, F. (2015), Expérimentation des innovations sur les territoires publics, *Déployer l'innovation : Méthodes, outils, pilotage et cas d'étude,* Techniques de l'Ingénieur, Paris, France.

Foreword

In this chapter, we delve into the topic of innovation in urban area, before focusing on the context of innovative startups. The aim of this chapter is to understand the challenges related to designing and experimenting innovative products and services by city-based startups. The real-world experimentation of these products and services is analyzed at the scale of the City of Paris.

Abstract: Major cities attract innovators and devote public resources to host and support startup companies that develop user-centered innovations. More specifically, they grant startups access to public areas and facilities so that they may conduct real-world experiments before launching their products and services on the market. However, as observed in the City of Paris, there is generally no clear framework that systematically explores the question of improving the performances of such

experiments. An interdisciplinary review of the literature in the fields of urban innovation and management of innovation confirms this observation. In this paper, we first introduce Urban-Centered Innovation (UrCI) as a new category of innovative value proposition developed by city-based startups. Subsequently, we analyze 132 real-world experimentation projects of UrCI conducted by innovative startups in Paris to identify the areas where the effectiveness of these experiments could be improved. Then, based on this analysis we propose a set of operational guidelines and general recommendations addressed to urban public actors. Finally, the relevance of the results obtained is verified through semi-directive interviews with the actors of urban innovation.

Keywords: innovation district, Living lab, Urban lab, urban-centered innovation, real-world experimentation, urban area.

1.1. Introduction

Within the rise of “Innovation Districts” (see (Katz and Wagner, 2014)), the geography of innovation has been shifting from conventional suburban techno-corporate hubs, such as the Silicon Valley, to the core of major cities (Florida and Mellander, 2016).

Indeed, major cities offer perfect environments for *networking*, as anchor institutions, startups, large corporations and residents’ communities can connect to each other to form clusters (Katz and Wagner, 2014). As such, urban areas become *hubs of innovation* that strengthen the socio-economic proximity, i.e., the proximity of resources and mutualized activities of stakeholders thanks to convenient urban infrastructures and affordable office places. Furthermore, large cities deal with important urban challenges, such as urban mobility, healthcare, and energy efficiency, that can be addressed by innovators.

These features of urban areas attract a new wave of innovative entrepreneurs who establish their startup offices in the core of main cities. Such city-based startups design and deliver innovative product-service that can be called: Urban-Centered Innovation (UrCI). Even though all types of innovation are somehow linked to the urban area, it is important to characterize UrCI as a new concept insofar as, compared to user-centered innovation, it has differentiating characteristics such as: tackling urban challenges (e.g., urban mobility and public health), evolving in the multi-stakeholder environment of a city, facilitating access to public procurements, real-world experimenting in the urban area to obtain broader users’ feedback.

To facilitate real-world experiments, cities adopt user-centric techniques such as *Living labs* and *Urban labs*. Living labs consist in “*experimentation environments in*

which technology is given shape in real-world contexts and in which (end) users are considered 'co-producers'" (Ballon et al., 2005). In the case of Urban labs, "*the city can provide a specific area for testing or allow companies to request real-life testing environments*" (Mulas et al., 2016). There are several Living and Urban labs in major metropolitan cities, including the city of Paris which has been recognized as one of the most leading city in research and innovation around the world (InnovationCities, 2017).

This research focuses on action plans of the City of Paris for supporting the development of urban innovation. Indeed, since the City has created an ad hoc organization, called Urban Lab (http://urbanlab.parisandco.paris), to help entrepreneurs conducting real-world experiments of their products and services. In addition, in partnership with the French Public Investment Bank (BPI France), the City has set up a fund called PIA (*Paris Innovation Amorçage*) to financially support the development of UrCI and its real-world experiments.

Since its creation, Urban Lab has supervised the whole process of preparing, selecting, running, and evaluating several hundreds of real-world experimentation projects conducted by city-based startups. This process calls for important investments in terms of time, financial and human resources. Besides, the results of these experiments help startups and public actors taking important decisions regarding the launch or purchase of an innovative product or service. More specifically, the results of such real-world experiments raise the interest of public purchasers who constantly look for tangible proofs to consolidate their complex innovation procurement processes.

Therefore, one may observe that the effectiveness of the whole experimentation process (from preparatory stages to final evaluations) is a true concern, both for startups and for urban stakeholders.

Despite extant literature in the field of urban innovation and its associated disciplines, no research works, to our knowledge, address the ways of enhancing the performances of urban real-world experiments and come up with practical recommendations to public actors on this topic.

Therefore, it is worthwhile to raise the questions of: **how to improve the effectiveness of such real-world experiments, considering the scarce resources of public stakeholders and startups?**

This research aims at responding to above-mentioned question, first by diagnosing UrCI and their real-world experiments, and second by providing a set of decision-making supports to improve the effectiveness of real-world experiments of UrCI. To

achieve these objectives, our research method consists in a qualitative analysis of 132 real-world experimentation projects at the scale of the City of Paris.

From an operational point of view, the recommendations formulated in our research can contribute to a better decision-making of public actors in supporting urban-centered innovative products and services. From an academic stance, the results of this research can bring an added-value to a broader understanding of the evaluation and selection of urban innovation.

The structure of this paper is as follows. In Section 1.2, the related literature is analyzed. Section 1.3 details the research method of this study (i.e., how it is carried out). In Section 1.4, we provide a set of descriptive models to investigate Urban-Centered Innovation. Section 1.5 investigates the process of real-world experimentation through a case study in the context of the City of Paris. In Section 1.6, the formulated recommendations of this research are presented. Finally, Section 1.7 discusses the significance of the results as well as their limitations.

1.2. Background literature

This literature review covers the fields of socio-economics of innovation as well as the management of innovation in its very broad sense. A primary study of the related theoretical background shows that cities not only become a relevant platform for innovation (see subsection 0), but that they have also become a living laboratory for the test and validation of innovative value offers developed by startups (see subsection 1.2.2).

1.2.1. City as a relevant hub for fostering innovation

Authors argue that firms cluster in agglomerations to increase their creativity and productivity. The notion of “cluster”, theorized by (Porter, 1998, 2000), consists in sharing ideas and practices between companies. This model is widely considered as beneficial for urban entrepreneurial firms as it facilitates synergy and provides agglomeration externalities such as cost saving by sharing common infrastructures (Lechner and Dowling, 2003). For instance, the recent propagation of business incubators and co-working places in the core of large cities proves the strength of cluster models.

However, this local economic growth is not only motivated by the access to urban infrastructures and facilities. A large body of research argues that it is the *interactions between stakeholders* in an urban realm that generate and accelerate the development of new ideas and projects (see, e.g., (Elfring and Hulsink, 2007; Powell et al., 1996)).

Thus, inside cities, a dense network of stakeholders is forged and stimulates *cluster-based interactions* (Gutzmer, 2015).

Based on the analysis of the data of cell-phone connections and social networks, (Pan et al., 2013) demonstrate that cluster-based interactions are accelerated when people *bump into each other*. Due to bumping and *collisionable* activities spontaneous networks of individuals form around innovative ideas and projects (Mulas et al., 2016). These networks foster collaborative links, strengthen the generation of new ideas, support firms to penetrate new markets, and become a propitious ground for testing innovative products and services.

1.2.2. City as a living innovation laboratory

Cities (such as Boston, Barcelona, Helsinki, and Paris) establish places such as incubators, co-working places, Fab labs (manufacturing technologies to the service of creators), Living labs, Urban labs and City labs (Mulas et al., 2016; Almirall and Wareham, 2011). As such, public organizations devote time, urban facilities and resources to real-world experiments of innovative products and services.

Most authors define Living lab and Urban lab as user-centric concepts for the exploration of innovative ideas, prototyping, experimenting, validating, and refining complex solutions in multiple and evolving real-life contexts such as in cities (see, e.g., (Eriksson et al., 2005; Dell'Era and Landoni, 2014)).

A variety of techniques are used in the context of such labs. The co-creation or co-design with users is one of these techniques that remains an essential pillar of Living and Urban labs (Ståhlbröst, 2008; Juujärvi and Pesso, 2013). Among others, the launch of co-ideation platforms to solve the urban problems is given an extensive attention in recent years by urban stakeholders (see for instance (Pallot et al., 2010)). Nevertheless, it seems that the efficient involvement of users is far from apparent and that the co-creation turns out to be insufficient, as users and their underlying problems to be solved are often neglected (Eriksson et al., 2005; Niitamo et al., 2006; den Ouden et al., 2016).

In this context, one may question the effectiveness of the whole process of real-world experiments where the key stakeholders - for whom a product or service is designed - as well as their needs, are not systematically explored. It is also legitimate to ask whether the municipality can fulfil its mission in helping innovators conduct effective real-world experiments.

This research focuses therefore on diagnosing and improving real-world experiments of products and services designed by city-based startups. The next section explains the method used in this research.

1.3. Research method

This research is carried out in tight collaboration with the Innovation Office of the Department of Economic Development of the City of Paris and with the Parisian Urban Lab. The operational issue of this research consists in better supporting the whole process of real-world experiments of UrCI to help startups create value and thus foster the local economic development. However, this is a complex issue as, for the time being, no clear diagnosis has been made on the whole process to come up with relevant decision-making supports.

In this situation, it seems reasonable to base our research method on "action-research" because: this research deals with a complex operational issue, it is carried out as a participatory activity with the City and Urban Lab, and it follows the sequence of four major steps that are adapted from (Yannou and Petiot, 2011):

1) Observation of current operational practices at the scale of the City and Urban Lab to come up with descriptive models;
2) Identification of areas of improvement of real-world experiments of UrCI;
3) Proposition of a set of prescriptive models (operational guidelines and general recommendations);
4) Deployment of guidelines to globally assess the organizational acceptance.

The first step of this research consists in a qualitative study of executive summaries of 132 real-world experimentation projects of UrCI in parallel with a review of the relevant literature regarding specific topics, such as innovation ecosystem and stakeholder network analysis. The outcome of the first step includes a detailed analysis of the innovation ecosystem and of the stakeholder network, as well as a set of UrCI characteristics.

Subsequently, in the second step, to better identify the possible lacks and areas of improvement, investigations continue with an example of experimentation project in the field of tourism.

In the third step, new diagnostic models are proposed and a set of recommendations to public actors are provided. The latter is then brought to the attention of public

actors, during the fourth step of this research, for their feedbacks and for assessing their global acceptance.

The four methodological steps that we have followed are scrutinized in following sections of this paper.

1.4. Observations and descriptive models

In this section, our observations lead to the identification of three descriptive models. First, we set the perimeter of our observations to acquire a global vision of the urban innovation ecosystem. Second, we outline the network of stakeholders involved in this ecosystem. Third, we detail the main characteristics of Urban-Centered Innovation (UrCI).

1.4.1. Urban innovation ecosystem

(Nambisan and Baron, 2013) mention that "*an innovation ecosystem is bound together by common goals and the need to leverage one another's knowledge and capabilities and coevolve to achieve these goals*." Based on this definition, a city can be considered as a complex innovation ecosystem (see, e.g., (van Winden et al., 2014; Crowley, 2011)) that contains several components such as human capital, urban firms, entrepreneurs, and institutions.

These components can be distinguished as several nested layers (Vanhaverbeke and Cloodt, 2006). A representation of these layers is provided in the map generated by Innovation Leader (an independent media organization) (InnovationLeader, 2017). Inspired by this map, in Figure 2, we propose a synthetic vision of the urban innovation ecosystem. Following this vision, the urban area is characterized as a complex socio-technical structure consisting not only of physical components such as building and roads, but also of network of stakeholders. The latter includes public organizations, private stakeholders, and startups. Finally, those startups design, experiments, and commercialize value propositions.

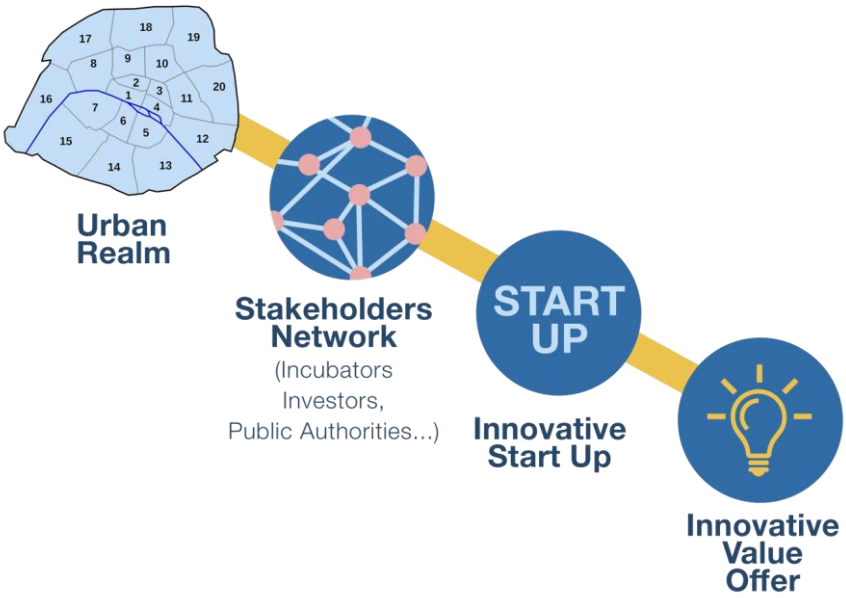


Figure 2. Urban innovation ecosystem nested layers

The definition of the urban innovation ecosystem can be considered as a first descriptive model which encompasses the four above-mentioned nested layers. In the following subsection, we focus on the network of urban stakeholders.

1.4.2. Urban innovation stakeholder value network

A stakeholder in a system, e.g., in a corporation, project or government, is defined as "*any group or individual who can affect or is affected by the achievement of the organization's objectives*" (Freeman, 2010). Stakeholders have some interests, influences, and key roles in the system. They may include *actors* that might be humans such as end-users and the mayor of a city. More often, stakeholders in a system are *mapped* to render a holistic vision of their strategic position and value exchanges. The aim of this mapping is to provide relevant managerial guidance to deciders (Feng, 2013).

Several techniques help to map stakeholders and study their convergences and divergences when they face a set of associated stakes and objectives. For instance, Godet (Godet, 2000) developed strategic prospective methods for stakeholder analysis by using quantitative combinatory matrix tools, called MACTOR and MICMAC. Dependency structure matrices are also used to analyze the Stakeholder Value Networks (SVN) in a multinational energy project (Feng, 2013) and in NASA programs (Sutherland, 2009).

In our context, the mapping of innovation-related stakeholders is not an easy task due to the myriad configurations of stakeholders that are unstable over time. Therefore, in the following we aim at visually mapping the clustering of stakeholders around an urban-centered innovative product and service to provide a holistic schematic of the configurations and interactions of different stakeholders. To do so, the SVN technique seems well-adapted insofar as it allows to move beyond the structural and institutional aspects of stakeholders to identify archetypical value flows between them.

Our investigations on 132 experimentation projects result in the identification of 12 main stakeholders according to their key roles and involvement in the process of experimentation. For instance, Urban Lab is qualified here as an experimentation facilitator. The startup company is characterized by its urban-centered innovative product of service as a driver of this clustering of stakeholders.

The identified stakeholders are then listed in dependency structure matrices to study their dual relationships, i.e., input and output value flows of each stakeholder. As depicted in Figure 3, in total 32 value flows are identified and categorized into six archetypical value patterns. These value patterns can be either material (such as providing a product or service from supplier to startup) or immaterial (such as policy decisions).

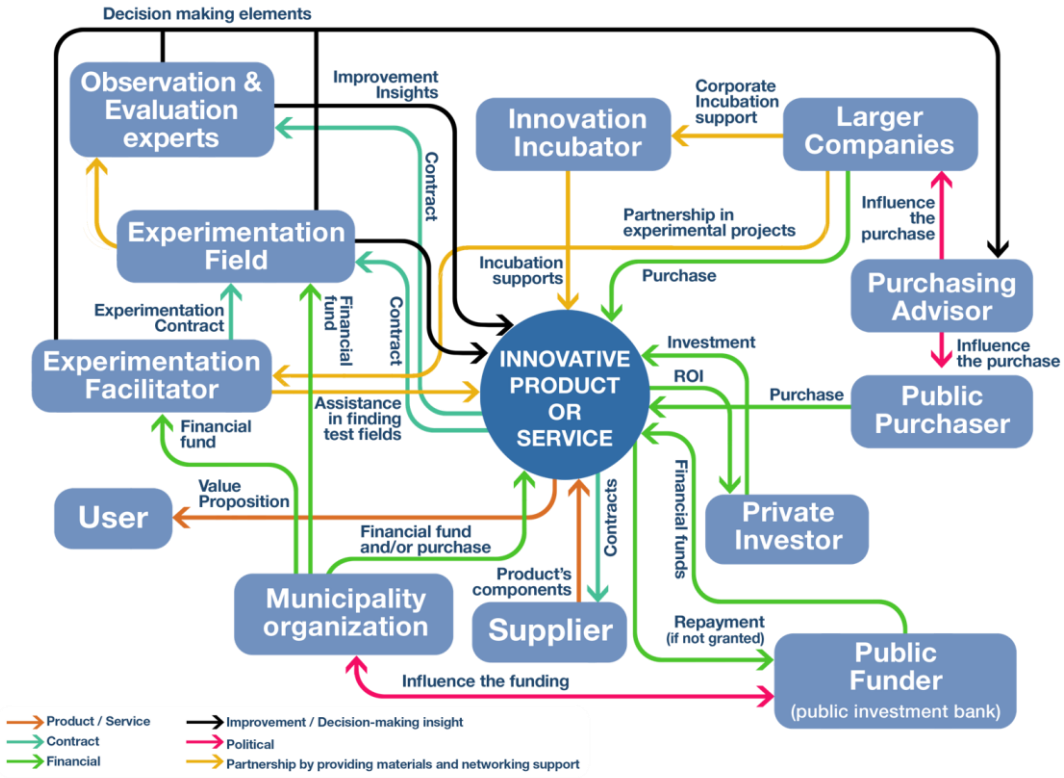


Figure 3. Parisian urban innovation Stakeholder Value Network (SVN)

Even though this visual representation (see Figure 3) does not allow quantifying the value flows, it remains useful as a first attempt to depict stakeholders' complex relationships. This map is a primary descriptive model that helps improve the perception of public urban actors about the clustering of stakeholders. Later, this model can be used for prospective purposes.

As Urban-Centered Innovation (UrCI) is the focal point of this network of stakeholders, it is necessary to focus on UrCI main characteristics in the following subsection.

1.4.3. Main characteristics of Urban-Centered Innovation

A third descriptive model contains five main characteristics of UrCI based on the identification of common patterns between the 132 studied experimentation projects. These characteristics are specific to UrCI that differentiate them from other categories of innovative products and services. The list of these characteristics is as follows:

- **Complexity of value flows between stakeholders**: this is indeed a fist conclusion drawn from the interpretation of the stakeholder value network map (depicted in Figure 3). The innovative product or service developed by a startup can be experimented, financially supported and purchased in an environment

of complex value exchanges between stakeholders. Within the rise of innovation districts, the municipality plays a crucial role in this complex value network.

- **Emergence of a new role of municipality organization as an innovation facilitator and as the financial supporter of UrCI**: this new role differs from traditional Public-Private Partnerships (PPP) and consists in providing material assistance (such as affordable office places in incubators, prototyping labs and co-working spaces), organization of innovation events and rewards to encourage innovative entrepreneurs, and experimentation facilitation service so that startups can stage real-world experiments of their value offers.

- **Emergence of new products and services aiming at creating high socio-economic values**: the claim of innovative startups is to meet and respond a marketplace need or problem. Therefore, they aim at responding to unsolved problems and contributing to a better quality of life of residents (and tourists) of a city. Such products and services become one of the procurement priorities of public purchasers.

- **Growing willingness of entrepreneurs to access to a public procurement market**: the development of UrCI enables startups to scale up their business by supplying a very large demand as big as the city administration or an important part of the population. Thus, startups focus on more B2A (Business to Administration) or B2A2C (Business to Administration to City residents/tourists) models. From the administrative side of these models, public purchasers require solid proofs on the value creation potential of startup's products and services. However, these proofs are generally inexistent insofar as it is necessary to experiment and verify them in real-life situations.

- **Necessity of conducting real-world experiments to gather proofs of concept and proofs of value before the launch of products and services**: innovators are eagerly considering opportunities to showcase their innovation to public and private organizations and public local stakeholders commit considerable resources to grant startups access to urban *experimentation fields* (see Figure 3). The results of real-world experiments enable startups to better manage uncertainties and risks before the launch of their value offer. Purchasers and purchasing advisors expect tangible proofs from those experiments to make decisions. Therefore, the results of experiments are crucial for startup per se but also for other stakeholders.

In the following, we focus on the fifth identified characteristic as it involves marshalling important resources and several stakeholders. A case study of real-world experimentation project is analyzed to identify the areas of improvement.

1.5. Identification of areas of improvement in the process of conducting real-world experiments of UrCI

As mentioned in the second step of our action-research, the purpose of this section is to understand whether the current process of real-world experiments is effective and if it truly enables to generate new knowledge for refining and improving the startup's value offer.

The case of a typical real-world experimentation project of a touristic solution in the context of the City of Paris is studied in this section. For this project, the City has engaged significant financial and human resources during six months of experimentation.

In the following, the general process of such experiments is divided into a sequence of four actions: (i) preparation, (ii) selection, (iii) design of real-world experiments, and (iv) conducting experiments and evaluation.

1.5.1. Preparation of the call for experimentation projects

First, Urban Lab and the City identify a theme for experimentation. This is usually performed by *benchmarking* a set of existing solutions for touristic information and urban signage already tested and deployed in large capital cities. Nevertheless, the issue with such studies is that not all large capital cities are comparable to Paris due to their different urban configuration and tourist populations. Indeed, the benchmarking study is done with online researches without necessarily surveying tourists and collecting data regarding their needs and problems to be solved. Here, the identified theme for the call for experimentation projects is the augmented reality solutions to improve the experience of tourists while walking inside the urban area. The specified theme is therefore solution-oriented rather than being focused on users' problems to be solved. This issue is also observed by an urban entrepreneur in the United States who mentions that: "*city governments need to get out of procuring by specifying the solution they want. What they should do is specify the problem they want to solve... and then allow the market to inspire them to find the best solutions*" (Swope, 2014).

1.5.2. Selection of projects

After the publication of the call for experimentation projects, applicant startups are auditioned and selected. In this case, a startup developing a technology for scanning smart logos and displaying augmented reality information on smartphone and tablet is selected. The selected startup has applied to the call for projects with *proposing* a specific usage of its technology that can provide touristic information in an urban area. This usage of the technology is not yet developed. Therefore, the technology is immature and it must be tested and matured through real-world experiments. The promise of value is once the smart logo is scanned by a smartphone, directions and touristic information on a historical monument or place can be displayed on screen as shown in Figure 4.

Figure 4. Augmented reality smartphone application for touristic information

This project is selected by a jury composed of City and Urban Lab actors after having auditioned three other innovative projects in the field of touristic information. According to the jury, this project proves to be the most innovative because of its *augmented reality feature* which makes it more innovative. Other selection criteria are unknown, since there is no selection-grid or process apart from the intuition and common sense of jury members. We therefore observe that the selection process is not systematic and needs to be improved.

1.5.3. Design of real-world experiments

Once the project is selected, the startup starts designing and developing smart logos as well as an ad hoc smartphone application. At the same time, several internal services of the City must coordinate and set the field for trials. For instance, the

transportation services fix the physical logos (see in Figure 4) in the streets by respecting complex road security measures. The architecture services must authorize the installation of logos on classified historical buildings. The role of the cultural and tourism affairs is to provide the content for the smartphone application. Even though, there is need for an efficient coordination and management between several urban services, this not always the case, because the coordination of such projects is not predefined for urban services. Indeed, each real-world experiment of UrCI may require multiple and unusual coordination between multiple actors and services. If this coordination is not well-defined the design of real-world experiments can become a time-consuming and trail-and-error task.

1.5.4. Conducting experiments and evaluation

Once experiments are conducted, City and startup resources are dedicated to the follow-up and evaluation. However, as the evaluation methods and tools are not identified beforehand, it becomes a time-consuming and inefficient task.

The results of this evaluation shows that only *eight* users have downloaded the smartphone application. The average usage time is less than 1 minute! This result shows that the whole investments and complex process of experimentation has a very little impact (or even zero impact) to create value. Therefore, the promise of creating socio-economic value is inexistence.

In summary, our case study, which represents a typical case of real-world experimentation projects of UrCI, showed that there are important issues with regards to each step of the process of experimentation. These issues are:

- the lack of involving users and their problems from the early steps of the experimentation process;
- the inexistence of a selection-grid and a set of criteria to select a relevant UrCI to be experimented;
- the lack of protocol for coordinating the actors and organizations involved in an experimentation project;
- the inadequacy of evaluation methods and tools with the objectives of experiments.

To tackle these issues, prescriptive models are outlined in the following sections.

1.6. Proposition of operational guidelines for an enhanced monitoring of the experimentation process

Based on the third step of our action-research (see Section 1.3), this section proposes a set of operational guidelines, each responding to an issue mentioned in the previous chapter). The purpose of this section is to help enhance the effectiveness of real-world experiments of UrCI.

1.6.1. Preparation of the call for experimentation projects: towards an enhanced exploration of users and their problems

The lack exploration of users' problems has led to experiment a specific solution while the problem to be solved remained unknown. Therefore, the starting point of a call for experimentation projects must focus on the identification of a *useful problem* (i.e., an unsolved or poorly-solved problem of users) instead of merely considering other existing solution regardless of their relevance for users. To do so, a systematic exploration of users' problems must be conducted.

There are several *problem exploration techniques* that can be used to acquire an in-depth knowledge regarding users, their behavior, and daily life problems. These techniques are among others:

- surveys on users' jobs-to-be-done (see (Christensen, 2013; Ulwick, 2016)), pains or sufferings, behaviors, and daily-life problems;
- interviewing users by "*coming out of the buildings*" instead of merely conducting online researches;
- organization of field visits with related-experts;
- interview of experts inside and outside the City administration;
- analyzing causes and consequences of important problems (see for instance (Yannou et al., 2018)). An important problem is a problem that has serious consequences (e.g., for a tourist it can be getting lost in the streets of a city and consequently wasting time or missing a transportation); and
- identifying and eliciting **important end-users' problems occurring in frequent usage situations** from the early design stages, as advocated by (Yannou, Cluzel, et al., 2016).

Ultimately, the problem exploration task, in parallel with the identification of the existing solutions, must enable to highlight the important and frequent problems for which the existing solutions are not satisfactory enough. These problems are called

Value Buckets by (Yannou, Cluzel, et al., 2016) and (Lamé et al., 2017). Authors have also proposed an algorithm, called DSM-Value Bucket, enables to systematically compute these value buckets. The outcome of this algorithm can help quantify and prioritize important and frequent problems to be addressed through real-world experiments.

A dedicated "*problem watch*" at the level of the City of Paris and Urban Lab may conduct systematic exploration of users' problem with the help of the above-mentioned techniques and tool.

1.6.2. Selection of experimentation projects: proposition for selection criteria and a decision-making tool

Very often, the selection process merely sticks to the technical requirements of the call for projects or tender. It is therefore necessary to re-think the selection process by thoroughly questioning the experimentation project of a startup. Previous research works point out the need for consolidating the selection process to filter and prioritize those projects that create real socio-economic value for users and that are thus a legitimate recipient of public fund (Yannou, Farel, et al., 2016).

A set of *innovativeness* indicators called UNPC proofs (standing for *Usefulness, Newness, Profitability* and *Concept*) are already developed, tested, and validated by (Yannou, Farel, et al., 2016). This set of indicators enable to select and prioritize those innovations with higher likelihood of value creation. Therefore, these proofs can be easily used as a selection framework for UrCI. However, to better cover the main characteristics of UrCI (mentioned in 1.4.3), it seems important to cover the interactions of innovative startups with other stakeholders in the urban area. Indeed, the business of a product and service which is strong from the perspective of U, N, P, and C proofs, cannot be scaled up if it remains poorly-known and not-purchased. Consequently, it is convenient to propose a fifth proof, called proof of *Stakeholder network* (*S*), to the set of UNPC to obtain UNPC*S* proofs as briefly detailed in Table 1.

The *Stakeholder network* (*S*) proof is relevant in an entrepreneurial context as showed by authors in (Bekhradi et al., 2015). The evaluation of this indicator helps the jury of projects assess the awareness (or the excess of focus) of innovative entrepreneurs on the business networking and lobbying activities.

Table 1. UNPCS proofs

Proof type	Definition adapted to the case of UrCI
Proof of **Usefulness (U)**	is related to covering or responding to people's unsolved or poorly-solved problems.

Proof of **Newness (N)**	has three main components: • Real technological newness, possibly patentable (this is mostly the case of startups spun off from city anchor institutions); • Newness that citizens and customers appraise (e.g., intuitive urban signage); • Real usage newness (e.g., public touch displays).
Proof of **Profitability (P)**	is the expected economic profitability of a project for both startups and customers: • the total profit of producing one more product unit (for the startup). • the total profit of ownership which can also be associated to willingness-to-pay (for customers).
Proof of **Concept (C)**	is twofold: • for customers: a design solution must function in expected usage situations. • for startups: both technological and industrial feasibility must be considered.
Proof of **Stakeholder network (S)**	involves the entrepreneurs directly and has three main components: • ability to build partnerships for industrialization and commercialization of the product (e.g., finding suppliers and purchasing advisors, and building customer relationships…); • need of raising financial funds; • lobbying activities with public and private stakeholders.

To better assess each proof and to be able to rank and select projects, an evaluation grid containing 30 pieces of evidence (see the UNPCS scorecard in 1.11) is proposed as an operational decision-making tool for jury members. A quantification system is also considered, as explained by authors in (Yannou, Farel, et al., 2016), to assess the impact and the certainty of each piece of evidence. The project's rating is obtained by the sum of impact and certainty of the 30 pieces of evidence per project.

1.6.3. Design of real-world experiments: towards an improved coordination between actors and a wiser project management

As mentioned previously, because of the newness of such projects the organization and coordination of experimentation projects is challenging. This topic falls more within the scope of project and change management domains. However, to provide a comprehensive set of decision-making elements in this study, we merely propose a simplistic project management process which begins with conducting a feasibility study by the City and Urban Lab and following a close interaction with the startup company. This study must generate a synthetic report which is shared between the

involved stakeholders to designate the roles and missions of each stakeholder. Subsequently, the template of the stakeholder value network (as illustrated in Figure 3) can be used as a visual tool to lay out the possible scenarios of coordination between stakeholders around an experimentation project. Finally, a clear protocol and detailed roadmap must be outlined prior to the launch of experiments.

1.6.4. Conducting experiments and evaluation: choosing a relevant evaluation method

The same pieces of evidence of the UNPCS proofs (see 1.11) can serve as the components of a monitoring and evaluation grid. The evaluation of each piece of evidence can be done by the startup and then validated and verified by the administrative and operational services of the City and Urban Lab experts. Besides, visual charts such as radar chart can be rendered at different levels of the experimentation project to guide and monitor the startup's activities and consequently to generate improvement insights.

Beyond operational guidelines, two series of general recommendations from a high-level view are proposed in the following section.

1.7. General recommendations to foster urban-centered innovation through experiments

An effective innovation policy for real-world experiments of UrCI must focus on testing and procuring innovations by systematically capturing users' feedbacks and by exploring their problems.

1.7.1. Spurring the stakeholder network to systematically collect users' feedbacks in real-world experiments

In Figure 5, contrary to the network described in Figure 3, the users' feedback is depicted as a new value flow (extreme left part of the map) to be systematically captured through experiments. A relevant monitoring and evaluation mechanism must be set up to capture users' feedbacks during and at the end of experiments.

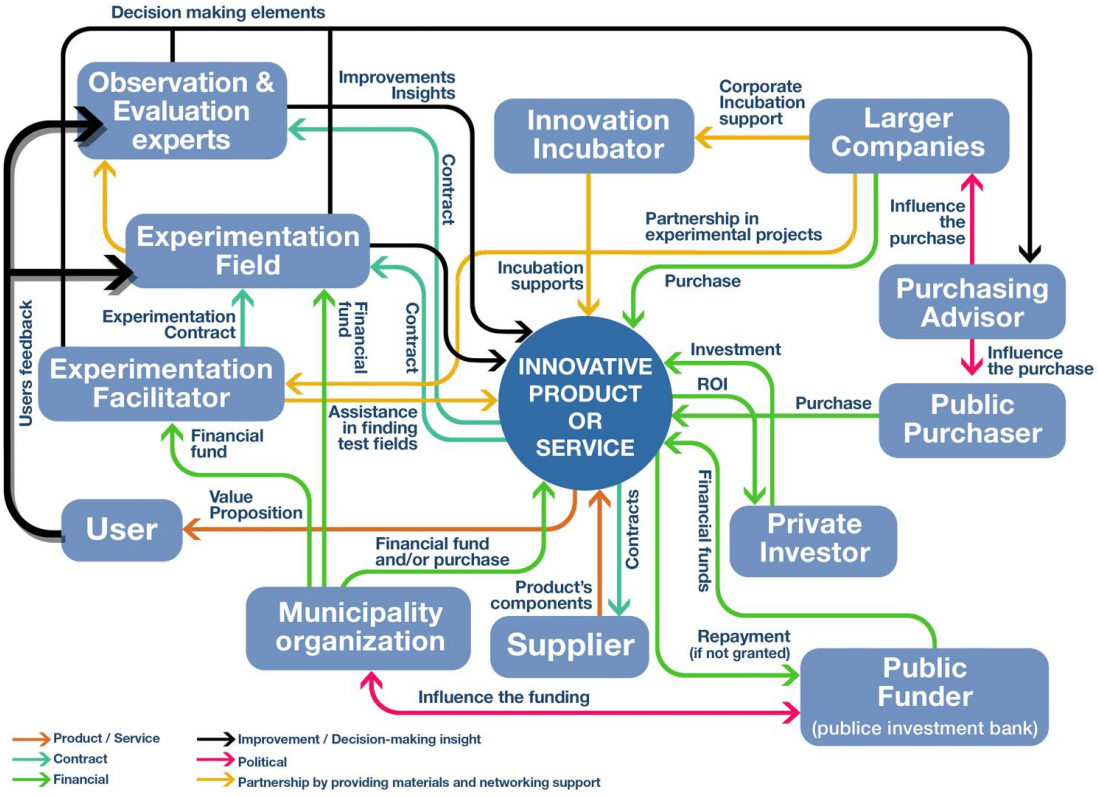


Figure 5. Stakeholder value network by systematically capturing users' feedbacks

The generated knowledge (or also called learning (see, e.g., (Thomke, 2014)) from real-world experiments of UrCI needs to be systematically documented and then easily extractable for future projects. This is the role of stakeholders such as Urban and Living labs to keep track of their project not merely regarding the technical aspects of the projects, their cost, lead-time, and complexities, but also record what has been learned about users, their problems, and behaviors.

1.7.2. Encouraging early design stage experimentation to reduce uncertainties before prototyping

The Open Innovation funnel (Chesbrough, 2003) crossed with the major Technology Readiness Level (TRL) (Mankins, 1995) can help better depict the maturity process of urban-centered innovation (see Figure 6).

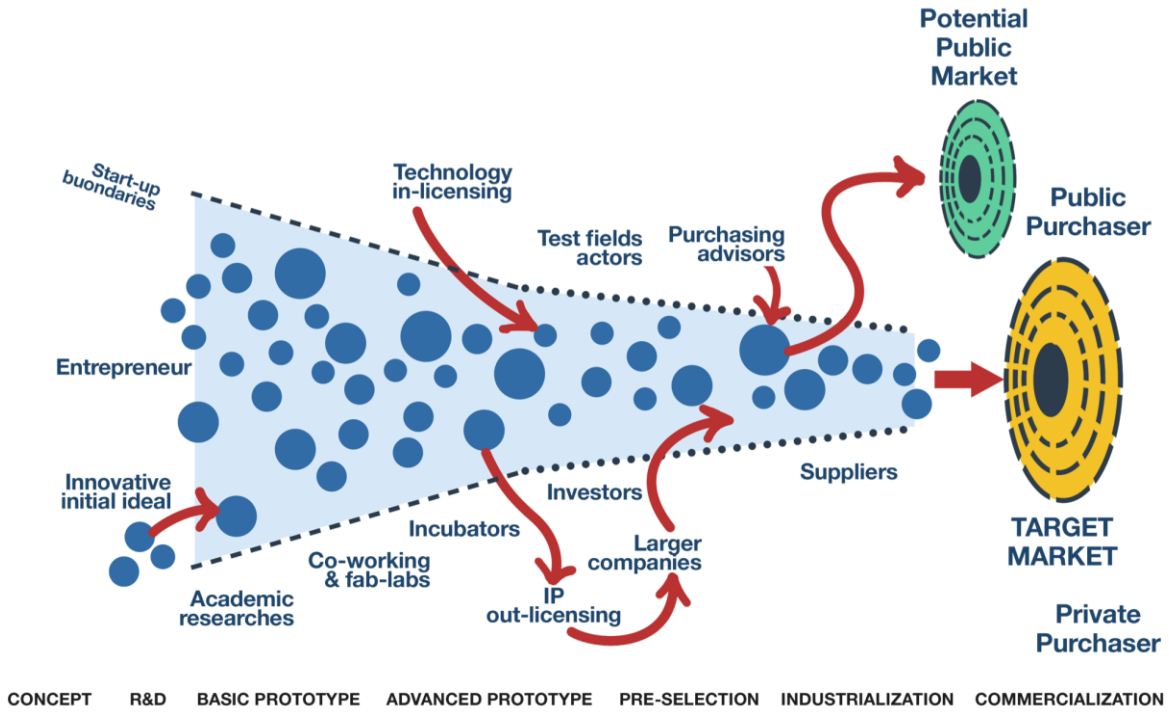


Figure 6. UrCI maturation from the perspective of Open Innovation and TRL

Most often, field trials (or real-world experiments) are defined as the test of advanced prototypes hence from higher maturity levels. The studied practices show that real-world experiments are launched from late stages of maturity without systematically undertaking users' and other stakeholders' problems to be solved.

Therefore, more porous boundaries must be set at the front end of innovation to reduce uncertainties and risks from early innovation stages instead of launching costly and time-consuming experiments. In Figure 7, we strongly recommend a switch from the current state to more *need seeker* (see (Jaruzelski et al., 2016)) urban-centered innovation based on systematic exploration of overlooked users' problems from early design stages. The early involvement of users' problems in the context of Living and Urban labs leads to filtering ideas and projects that are useless and not-perceived as innovative by users.

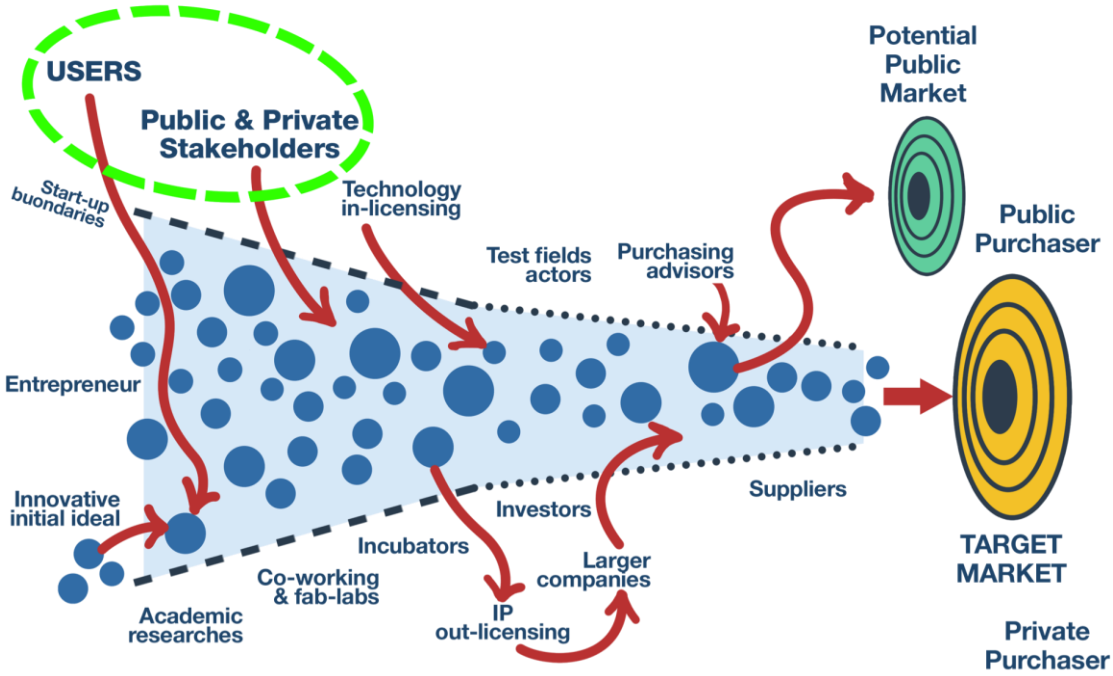


Figure 7. Boosting need seeker innovation strategy in the context of UrCI

In practical terms, the City administration and/or Living and Urban labs can provide relevant environment and tools to startups for rigorously explore and identify a problem to be solved rather than responding to a real-world call for projects with merely a promise of value creation. In other words, urban stakeholders must dedicate a part of their resources to identify a useful problem in the sense of value buckets (see subsection 1.6.1).

1.8. Relevance of the proposed models and their and limitations

Consistent with the fourth and last step of our action-research (see Section 1.3), we conduct a set of semi-directive interviews with the actors of the City of Paris and Urban Lab to assess the relevance of the results and their possible limitations.

These interviews are carried out with a panel of five participants composed of: two Officials of the Innovation Office of the Department of Economic Development of the City of Paris, three innovation Project Managers of Urban Lab. The following topics are covered by these interviews: (i) general impressions regarding the proposed models, (ii) comments on their usefulness, (iii) further implications for operational stakeholders, and (iv) possible limitations of these models. In the following, a summary of participants' responses and comments is provided.

Their primary collective impression is that the proposed descriptive and prescriptive models are relevant as a first attempt to embrace the concept of UrCI and its real-world experiments.

Regarding the usefulness of the developed models, descriptive models cannot be deployed directly in an operational context. Among these models, the graphical template of the map of urban innovation stakeholders (see Figure 3) is considered as a practical tool. However, this template may be reductionist of the dynamic evolution of stakeholders' key roles. Aware of this limitation, authors have emphasized that this model represents a static vision of urban innovation stakeholders and must be adapted to given context of UrCI.

The last descriptive model which characterizes UrCI is validated by the participants in the interviews. However, they emphasize that the public procurement and B2A (Business to Administration) business model must be treated carefully, as the context of public procurement is complex from the legal point of view.

The operational guidelines, presented in Section 1.6, can effectively support the decision-making process of the actors of the City and Urban Lab. Indeed, the participants in interviews appreciate the originality of the questions raised in this research regarding the effectiveness of the process of real-world experiments.

However, the interviewees from the City inform us that even though the operational guidelines provide significant efficiency, their implementation may require important time investment. Surprisingly, unlike participants from the City, the Project Managers of Urban Lab mention that the UNPCS can help better pre-selecting startups for experimentation. Therefore, they are willing to transform the UNPCS proofs as well as their pieces of evidence into a check-list for interviewing startups when they meet them for the first time.

Regarding the problem exploration process, the participants from the City confirm that this task must be conducted in a systematic way only in the case of call for projects or tender where there is need for prior research.

1.9. Conclusion and perspectives

In this research, we reflect on how to make more effective the real-world experiments of Urban-Centered Innovation (term coined by authors). The action-research deployed in this paper begins with the analysis of 132 experimentation projects that leads us to first identify a set of three descriptive models. These models enable to explain the urban innovation ecosystem, stakeholders, and the main characteristics of UrCI.

Subsequently, to improve the effectiveness of real-world experiments and based on the identified improvement areas from a case study, a set of operational guidelines and recommendations are provided to public actors. These guidelines emphasize the systematic exploration of users' problems prior to conducting real-world experiments. Another contribution of this research is a model for rigorously selecting and evaluating UrCI in the context of their real-world experiments.

The general recommendations of this research emphasize that the more relevant the innovative value offers are, the more one can expect prosperous urban economic development. The local economic development policy can thus be encouraged to develop a rather bottom up approach by gaining a superior understanding of users' problems from the early innovation stages instead of merely launching time- and resource-consuming experiments.

Our future research will fall under the continuity of the results of this paper and will intend to focus on micro-layers of the urban innovation ecosystem, i.e., innovative startups and their value offer. In future work, we will detail the case of other innovative startups that have participated in real-world experimentation projects of the City of Paris.

Acknowledgement

The authors gratefully thank the meaningful help of the following persons, who spent several hours with us in interviews: F., Moreau, M., Monjauze, M., Tessier, F., Chabbert, A., Festal, S., Zuber, M., Berthier, W., Bobiec, A., Godard, and A., Coussy. We also acknowledge the help of operational and administrative services of the City of Paris.

1.10. References

Almirall, E., and Wareham, J. (2011). Living Labs: arbiters of mid-and ground-level innovation. *Technology Analysis & Strategic Management, 23*(1), 87-102.

Ballon, P., Pierson, J., and Delaere, S. (2005). *Test and experimentation platforms for broadband innovation: Examining European practice.* Paper presented at the Conference Proceedings of 16th European Regional Conference by the International Telecommunications Society (ITS), Porto, Portugal. 4-6 September, 2005.

Bekhradi, A., Yannou, B., Cluzel, F., Chabbert, F., and Farel, R. (2015). *In Vivo In Situ Experimentation Projects by Innovative Cleantech Start-Ups in Paris*. Paper presented at the ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. http://dx.doi.org/10.1115/DETC2015-47631

Chesbrough, H. W. (2003). *Open innovation : the new imperative for creating and profiting from technology*. Boston, Mass.: Harvard Business School Press. 1578518377.

Christensen, C. (2013). *The innovator's dilemma: when new technologies cause great firms to fail*. Massachusetts, United States: Harvard Business Review Press. 9781633691780.

Crowley, L. (2011). Streets Ahead: What Makes a City Innovative? Retrieved from: http://reglab.dk/wordpress/wp-content/uploads/2016/05/306_streets_ahead3.pdf. Access date: July 2018.

Dell'Era, C., and Landoni, P. (2014). Living Lab: A methodology between user-centred design and participatory design. *Creativity and Innovation Management, 23*(2), 137-154.

den Ouden, E., Valkenburg, A., and Blok, S. (2016). *Exploring the future of living labs*. Retrieved from

Elfring, T., and Hulsink, W. (2007). Networking by entrepreneurs: Patterns of tie—formation in emerging organizations. *Organization Studies, 28*(12), 1849-1872.

Eriksson, M., Niitamo, V.-P., and Kulkki, S. (2005). State-of-the-art in utilizing Living Labs approach to user-centric ICT innovation-a European approach. *Lulea: Center for Distance-spanning Technology. Lulea University of Technology Sweden: Lulea*.

Feng, W. (2013). *Strategic Management for Large Engineering Projects: The Stakeholder Value Network Approach.* (PhD), Massachusetts Institute of Technology, Boston, US.

Florida, R., and Mellander, C. (2016). Rise of the Startup City. *California Management Review, 59*(1), 14-38. doi:doi:10.1177/0008125616683952

Freeman, R. E. (2010). *Strategic Management: A Stakeholder Approach*. Cambridge, United Kingdom: Cambridge University Press. 9780521151740.

Godet, M. (2000). The Art of Scenarios and Strategic Planning: Tools and Pitfalls. *Technological Forecasting and Social Change, 65*(1), 3-22. doi:http://dx.doi.org/10.1016/S0040-1625(99)00120-1

Gutzmer, A. (2015). *Urban Innovation Networks: Understanding the City as a Strategic Resource*: Springer. 3319246240.

InnovationCities. (2017). City innovation 10th annual classifications and rankings, 2016-2017. Retrieved from: http://www.innovation-cities.com/innovation-cities-index-2016-2017-global/9774. Access date: July 2018.

InnovationLeader. (2017). The Corporate Innovation Ecosystem: Understanding the Players, Tensions, and Key Strategic Questions. Retrieved from:

https://www.innovationleader.com/downloads/IL-CorporateInnovationEcosystem.pdf. Access date: July 2018.

Jaruzelski, B., Staak, V., and Shinozak, A. (2016, Winter 2016). Global Innovation 1000 : Software-as-a-Catalyst, The world's largest innovators are shifting the focus of their R&D investments from products to programming. *strategy+business*.

Juujärvi, S., and Pesso, K. (2013). Actor roles in an urban living lab: what can we learn from Suurpelto, Finland? *Technology Innovation Management Review, 3*(11).

Katz, B., and Wagner, J. (2014). The Rise of Innovation Districts: A New Geography of Innovation in America. *Brookings Institution.* Retrieved from: https://www.brookings.edu/wp-content/uploads/2016/07/InnovationDistricts1.pdf. Access date: July 2018.

Lamé, G., Yannou, B., and Cluzel, F. (2017). Usage-driven problem design for radical innovation in healthcare. *BMJ Innovations, 4*(1), 15-23.

Lechner, C., and Dowling, M. (2003). Firm networks: external relationships as sources for the growth and competitiveness of entrepreneurial firms. *Entrepreneurship & Regional Development, 15*(1), 1-26.

Mankins, J. C. (1995). *Technology readiness levels*. Retrieved from

Mulas, V., Minges, M., and Applebaum, H. (2016). Boosting Tech Innovation: Ecosystems in Cities: A Framework for Growth and Sustainability of Urban Tech Innovation Ecosystems. *innovations, 11*(1-2), 98-125.

Nambisan, S., and Baron, R. A. (2013). Entrepreneurship in innovation ecosystems: Entrepreneurs' self–regulatory processes and their implications for new venture success. *Entrepreneurship Theory and Practice, 37*(5), 1071-1097.

Niitamo, V.-P., Kulkki, S., Eriksson, M., and Hribernik, K. A. (2006). *State-of-the-art and good practice in the field of living labs.* Paper presented at the Technology Management Conference (ICE), 2006 IEEE International.

Pallot, M., Trousse, B., Senach, B., and Scapin, D. (2010). *Living lab research landscape: From user centred design and user experience towards user cocreation.* Paper presented at the First European Summer School" Living Labs".

Pan, W., Ghoshal, G., Krumme, C., Cebrian, M., and Pentland, A. (2013). Urban characteristics attributable to density-driven tie formation. *Nature communications, 4*.

Porter, M. E. (1998). *Clusters and the new economics of competition* (Vol. 76): Harvard Business Review Boston.

Porter, M. E. (2000). Location, competition, and economic development: Local clusters in a global economy. *Economic development quarterly, 14*(1), 15-34.

Powell, W. W., Koput, K. W., and Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative science quarterly*, 116-145.

Ståhlbröst, A. (2008). *Forming future IT: the living lab way of user involvement*. Luleå tekniska universitet.

Sutherland, T. A. (2009). *Stakeholder Value Network Analysis for Space-Based Earth Observation*. (Master's Thesis), MA: Massachusetts Institute of Technology, Cambridge.

Swope, C. (2014). How Barcelona and Philadelphia are turning procurement upside down. Retrieved from: https://www.citylab.com/life/2014/07/how-barcelona-and-philadelphia-are-turning-procurement-upside-down/374676/. Access date: July 2018.

Thomke, S. (2014). Accelerating Learning by Experimentation. In O. Gassmann and F. Schweitzer (Eds.), *Management of the Fuzzy Front End of Innovation* (pp. 125-140). Cham: Springer International Publishing.

Ulwick, A. W. (2016). *Jobs to be done: theory to practice*: Idea Bite Press. 0990576744.

van Winden, W., Braun, E., Otgaar, A., and Witte, J. J. (2014). *Urban Innovation Systems: What Makes Them Tick?* : Taylor & Francis. 9781317917458.

Vanhaverbeke, W., and Cloodt, M. (2006). Open innovation in value networks. *Open innovation: Researching a new paradigm*, 258-281.

Yannou, B., Cluzel, F., and Farel, R. (2016). Capturing the relevant problems leading to pain and usage driven innovations: the DSM Value Bucket algorithm. *Concurrent Engineering: Research and Applications*, 1 - 16. doi:10.1177/1063293x16666311

Yannou, B., Farel, R., Cluzel, F., Bekhradi, A., and Zimmer, B. (2016). The UNPC innovativeness set of indicators for idea or project selection and maturation in healthcare. *International Journal of Design Creativity and Innovation, 5*(3-4), 205-221. doi:10.1080/21650349.2016.1161562

Yannou, B., Lamé, G., and Cluzel, F. (2018). *Adapting the FBS model of designing for usage-driven innovation processes*. Paper presented at the IDETC/CIE 2018: International Design Engineering Technical Conferences/CIE: Computers and Information in Engineering, Montreal, Canada. August 2018.

Yannou, B., and Petiot, J.-F. (2011). A View of Design (and JMD): The French Perspective. *Journal of Mechanical Design, 133*(5), 050301-050301-050302. doi:10.1115/1.4004032

1.11. Appendix: proposition of a UNPCS scorecard

Proof Type	Evidence	**Impact** *[0; weak; average; strong]*	**Certainty** *[absent; some elements; credible elements; complete evidence]*
Proof of Usefulness (U)	Definition of the problem to be solved		
	Relevance of the identified usage situations		
	Definition of the value buckets and the ambition perimeter (a selection of value buckets)		
	Covering the identified value buckets		
	Systematic exploration of the existing solutions		
	Appropriateness of the project for other stakeholders		
Proof of Newness (N)	Knowledge of the value chain		
	Legal and patent watch		
	Technical and economic scouting		
	Degree of usage newness		
Proof of Profitability (P)	Financial management of the project development and experimentation		
	Cost breakdown structures		
	Sources of revenues		
	Identified sale channels		
	Willingness to pay of customers/end-users		
	Marginal cost of production		
	Relevance of the identified key resources to the project		
Proof of Concept (C)	Relevance of the identified key activities to the project		
	Description of the concept		
	Planning of the project's design activities		
	Degrees of skill and knowledge of the project provider or entrepreneur		
	Prototype development strategy		
	Project risk analysis		
	Project development milestones validation process		
	Products robustness and reliability of materials in extreme usage conditions		
Proof of Stakeholder network (S)	Relevance of project partners		
	Ability to introduce the project and communicate (skills in *pitch*)		
	Strategy for obtaining current or desired support for the project		
	Ability to fund the project development or experimentation via adapted fundraisings		
	Ability of lobbying or persuasion		

Chapter 2. Paper #2: Do innovative startups rigorously design and test a product or service?

This paper is submitted to the Journal of Small Business Management in May 2018, under the following reference:

- Bekhradi, A., Yannou, B., and Cluzel, F. (2018). Do innovative startups rigorously design and test a product or service?. *Submitted to Journal of Small Business Management*.

The conference paper which provides the basis of this paper is:

- Bekhradi, A., Yannou, B., Cluzel, F., Chabbert, F., and Farel, R. (2015). In Vivo In Situ Experimentation Projects by Innovative Cleantech Start-Ups in Paris. ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Boston, Massachusetts, United States. August 2015. http://dx.doi.org/10.1115/DETC2015-47631

Foreword

After having presented and analyzed the concept of Urban-Centered Innovation in the previous chapter, the following chapter covers the topic of design and testing practices of innovative startups. The focus of this dissertation is therefore switched from the urban-centered innovation to startups and to the core of their design and testing practices.

As discussed in chapter 1, to foster urban-centered innovations it is necessary to gain an in-depth knowledge about end-users and their problems to be solved. In chapter 2, we explore, through an investigation on 60 innovative startups, whether they rigorously explore end-users' problems when experimenting their products and services.

Abstract: This paper presents a framework to analyze design and testing practices of innovative startups. A scientific approach is then used to study why innovative

startups fail at the value proposition level. The results of interviews with a panel of 60 innovative startups show that despite the use of methods and tools, the main concern of startups in terms of testing of their prototype in real-life is to leverage business networking and lobbying instead of improving the maturity of their solution. A further analysis shows that the main reason for failure is their poor knowledge of end-users, arising from the misuse or lack of use of existing methods and tools.

Keywords: prototyping and testing, innovative startup, field trial, experimentation, failure reasons, FMECA, root cause analysis.

2.1. Introduction

An innovative startup or venture is an institution meant to create value by delivering a new product or service, and to scale up a business *under conditions of extreme uncertainty*. Several decision-making supports help entrepreneurs deal with uncertainties. These supports are (i) *theories*, which provide a rational explanation of entrepreneurial attitudes (see for instance (Sarasvathy, 2001), (ii) *frameworks*, which comprise a set of concepts and principles to make rules for launching a new business (see, e.g., (Blank, 2013a), and (iii) *methodologies,* which are theoretical foundations that suggest design and testing practices, techniques and tools (for example (Ries, 2011; Osterwalder and Pigneur, 2010). Since the boundaries between the above-mentioned supports are blurred, we shall call them all *methods and tools* or simply *"methods"* for the sake of simplicity. Their common claim is that: if their underlying concepts are correctly understood they can increase the likelihood of success of innovative startups and reduce their waste of time and resources.

However, despite of these methods, there is still much waste in startups: recent studies show that an important number of startup companies fail to create viable businesses (see, e.g., (Feinleib, 2011; Patel, 2015) or meet serious difficulties, more than older firms (Shepherd et al., 2000). These failures represent a heavy burden for local and national economies. Several reasons related to an entrepreneur's personality and skills can help explain these failures. However, there may also be underlying causes of failure at the level of the value proposition. It is thus instructive to focus on how startups design and test a value offer and why they fail to offer a real value to customers/users.

Based on this primary analysis, this paper follows a twofold objective, to understand (i) how innovative startups design a new product and service and how they perform tests to improve it, and (ii) why they fail while using existing methods and tools that claim to increase the likelihood of success on the market.

To meet these objectives, an extensive sat of data is collected from semi-directive interviews with a panel of 60 French startups that have all participated in real-world experiments (or field trials) organized by the City of Paris. These startups are financially supported by the Paris municipality with more than two million euros of grants and refundable assistance.

The initial purpose of these trials is to enable startup test and refine an innovative product and service with users in realistic conditions.

The products and services cover various topics, such as (see Figure 8): (a) green interactive bus stops, (b) energy-efficiency meter for public and service buildings, (c) tourist navigation system by scanning of physical codes, (d) washable diapers for Parisian childcare centers, (e) a memory-aid box for elderly Alzheimer patients living in municipal retirement institutes, (f) growing mushrooms on waste coffee grounds collected from Parisian cafés, and (g) self-service universal reading glasses in public places.

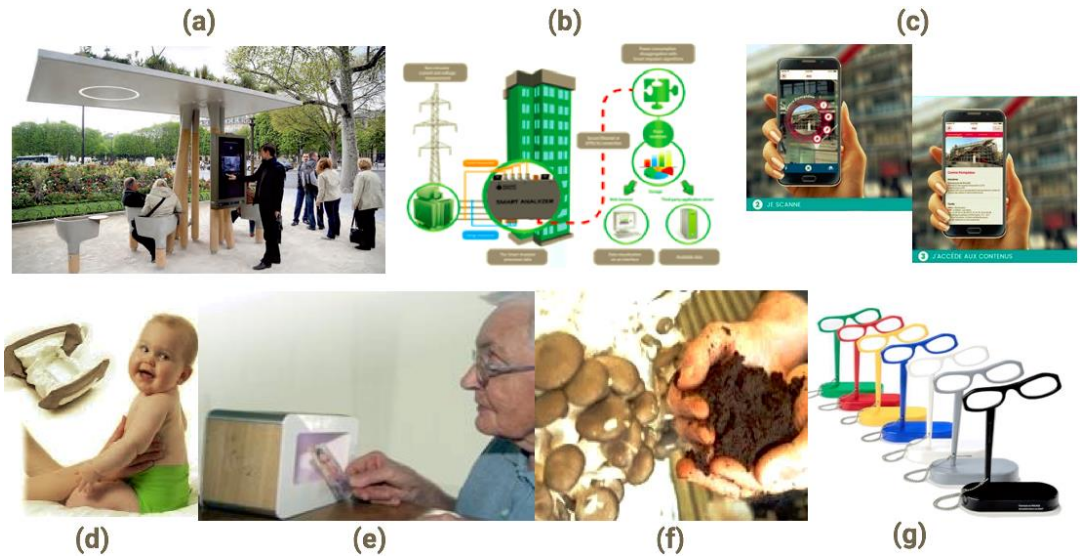


Figure 8. Examples of innovative products and services experimented in Paris

The aggregated data collected, through semi-directive interviews, over 60 startups show that they were all familiar with and applied a set of design and testing methods. Moreover, further survey on these startups indicates that 27% of them have failed in less than five years of operation on average.

Based on the survey results, this paper aims at making two contributions: first, providing a general framework with a set of quantitative indicators to analyze the relevance of design and testing practices of innovative startups; second, identifying

the underlying reasons why 27% of studied startups failed at the level of their value offer design.

The structure of this paper is the following. Section 2.2 outlines a literature review on design and testing methods. The context and the research method of this study are described in Section 2.3. In Section 2.4, the results obtained from the survey on 60 innovative startups are reported. Subsequently, Section 2.5 presents the data validation process. Finally, Section 2.6 discusses the significance of the results and their limitations.

2.2. Design and testing methods and tools for innovative entrepreneurs

The choices made by an entrepreneur can strongly influence the development of an innovation from its early fuzzy phases. These choices are generally grouped into how entrepreneurs *create*, *test* and *validate* an innovation. The related literature is therefore multidisciplinary and encompasses engineering design methods (see among others, (Fisher, 1937; Cross and Roy, 1989; Pahl and Beitz, 2013; Unger and Eppinger, 2011)), business and technology management (such as (Ries, 2011; Thomke and Manzi, 2014)), and economic and entrepreneurial practices and theories (see, e.g., (Kerr et al., 2014)).

These methods and tools are popular for innovative entrepreneurship or startup companies, but of course not limited to them. More specifically, there are methods tailored for entrepreneurship, for example: Customer Development (Blank, 2013a), Lean Startup (Ries, 2011), Business Model Canvas (Osterwalder and Pigneur, 2010), Value Proposition Design (Osterwalder et al., 2015) and Disciplined Entrepreneurship (Aulet, 2013). They may also be applied in new product development regardless of innovative project type (entrepreneurial or not) or company size, such as SWOT, Blue Ocean Strategy (Kim and Mauborgne, 2014), five forces (Porter, 2008b) and Value Chain (Porter, 2008a). Now, one may ask: why do these methods and tools exist? What do they contain? And what insights they are meant to generate?

Their purpose, more particularly in the context of startups, is to leverage creative problem solving and "*thinking outside the box*". For most authors, innovation follows a *chaotic* and *non-linear* sequence of events (Furr and Dyer, 2014) since innovation is equivalent of creative thinking loops are needed to reduce uncertainties. More than a process, there are also hands-on tools which can take the form of visual maps, canvases, checklists or indicators. One of these important tasks is testing or conducting experiments.

Experimentation is a scientific procedure that relies on repeatable observations and logical analysis of results. Experiments are largely used in human and natural sciences to gather sufficient evidence to support, refute or validate a hypothesis regarding an artefact (physical or virtual object), a process or a phenomenon to be tested. In the process of designing an innovation, experiments are frequent and are often performed on an artefact, called a prototype, which is "*a tangible artefact, not an abstract description that requires interpretation*" (Beaudouin-Lafon and Mackay, 2003). In engineering design, several prototyping techniques exist to create an "*approximation of the product along one or more dimensions of interest*" (Ulrich and Eppinger, 2015). These techniques include rapid (McDonald et al., 2001), throwaway, evolutionary (Davis, 1992), sequential and parallel prototyping (Dow et al., 2012). They can strongly influence the efficacy of the testing phase that is incorporated into the late stages of development processes (Ullman, 1992; Pahl and Beitz, 2013). A prototype serves as a verification and validation support, and if it is not well-suited to verifying design specifications or hypotheses, company resources can be greatly wasted.

In the innovative entrepreneurship literature, the Lean Startup approach (Ries, 2011) became very influential (Blank, 2013b) and popular (Hanshaw and Osterwalder, 2015) among startup companies. This approach is strongly inspired by Lean Thinking (see for instance (Womack and Jones, 1997) and agile software development approaches such as Test-Driven Development (Beck, 2003)) which relies on repeated short development cycles. One of the core principles of the Lean Startup is therefore *build-measure-learn* loops (see Figure 9).

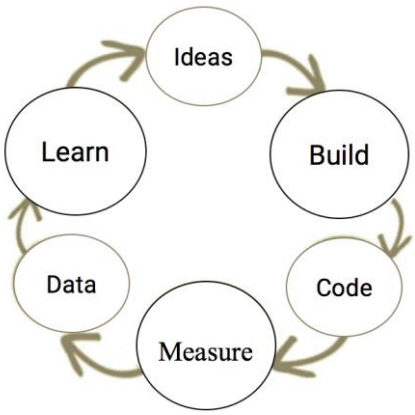


Figure 9. Lean Startup Build-Measure-Learn Loop, adapted from (Ries, 2011)

The Lean Startup approach thus follows an effectual reasoning (see (Sarasvathy, 2009)), where instead of identifying long-term objectives, a set of given means is devoted to performing iterative loop-based tests on an artefact – called Minimum Viable Product (MVP) – to capture new knowledge. The process of gaining knowledge is called *validated learning* (that is the amount of generated information that the

company can benefit from). Other work (Thomke, 2003; Thomke, 2014) suggests a similar loop-based experimentation approach called *Learning Cycle* through a four-step cycle (Design-Build-Run-Analyze).

Inspired by Lean Startup and Customer Development, (Osterwalder et al., 2015) suggest a testing process. The recent approach of Value Proposition Design (VPD) devotes a whole chapter to testing an innovation. The unit of progress is the validated learning about customers. Test hypotheses are generated following the analyses of the visual templates of Value Map, Customer Profile and Business Model Canvas (BMC) (see (Osterwalder et al., 2015)), filled in by startups and mainly based on their intuition. The BMC is considered as a lean startup tool. It is visual, composed of nine building blocks, and is used to design, test and build new business models. The BMC complements Kim and Mauborgne's Blue Ocean Strategy (Kim and Mauborgne, 2014) which prescribes the creation of new differentiating businesses by increasing value creation for customers, while eliminating costs for useless features.

In summary, despite the existence of a large of body of literature on methods and tools in innovative entrepreneurship, it is still hard to understand how, and through what processes, innovative startups design and experiment a product and service. Indeed, the existing literature is either focused on one specific method used by startups, or it does not systematically explore how startups deploy these methods. Besides, to our knowledge, no scientific research examines the question of startup failures and its potential link to the existing methods.

To tackle the identified issues, in what follows we describe a study carried out on a panel of 60 innovative startups.

2.3. Survey on design and testing practices of 60 innovative French startups

This survey aims at determining: how innovative startups design and test a new product, and to what extent the existing methods and tools are effective to design and test a product that responds to users' problems.

2.3.1. Survey context

This survey is conducted jointly with the City of Paris and Paris Urban Lab between 2014 and 2017. Urban Lab (http://urbanlab.parisandco.paris/) is indeed an ad hoc organization created by the City of Paris since 2009 to organize call for experimentation projects, and thus to facilitate the launch of real-world experiments (or field trials). These experiments are conducted by startup companies looking to test

their value proposition directly with users in real usage situations. To conduct this survey, authors have access to the files of a panel of 132 startups of the Urban Lab of which 60 have already finalized their tests.

Innovative startups conduct these experiments under a limited period of time (from one week to several months) and in real-life situations in an urban setting. All 60 startups are from innovation incubators and have already developed a prototype of their product or service; 45 of them (75%) were technology-oriented (i.e., the startup firm that has an innovative core (or platform) technology to make mature and to launch on the market). The rest were non-technological physical products (10%) or services (13%) across various business fields.

Hard though it is to categorize innovations in terms of a field or a specific industry, we have attempted to define some generic categories based on the call for experimentation topics defined by the City of Paris (Table 2). Since one of the City's major challenges is building energy efficiency, most of these startups have developed technology to diagnose energy consumption and to suggest incentive consumption scenarios. The question of urban mobility is also at the heart of most startup products and services (for example smartphone applications to suggest alternative walking paths through historical parts of the city).

Table 2. Categories of innovative value offers of the 60 innovative startups studied

Value Proposition Category	Examples	Percentage among 60 Studied Innovative Startups
Building Energy Efficiency	• *Air-purifying technology for semi-public spaces* • *Sensors and applications to for wiser energy consumption in residential buildings*	*35%*
Urban Mobility	• *Transformation of thermal vehicles into electric ones* • *CO_2 emission sensors to produce real-time maps of air pollution*	*18%*
Public Urban Furniture	• *Smart displays providing interactive information*	*12%*
Cultural Product or Service	• *Crowdfunding for the digitization of ancient books and documents in municipal specialized libraries*	*10%*
Healthcare Product or Service	• *Simplified tactile tablet with services and health components, designed to improve the quality of life and autonomy of elderly people at home*	*10%*

Public Green Spaces	• *Bio-intensive vegetable farm re-using urban organic waste in an urban environment*	*3%*
Waste Management	• *Economic incentive smartphone application for better recycling in large cities*	*3%*
Other Products or Services	• *Self-service universal reading glasses in public places*	*9%*

It is hard to be sure that a panel of startups is representative of a whole. However, all our 60 startups have a prototype to test, and 75% of them are technology-oriented, a figure close to the general percentage (73%) of techno-based startups according to a (Wu and Atkinson, 2017). In addition, a broad variety of innovation sectors is covered, and all 60 startups have been incubated and claim to develop an innovative product or service.

The municipality of Paris devotes much effort and considerable financial resources to supporting startups in their real-world experiments: in this case, more than two million euros are allocated to them to carry out these experiments. Given the scarcity of public funding and of human and test-field resources for these projects, it is of interest to analyze the efficacy of these experiments and of startup design and testing practices. The following subsection describes how this analysis was performed.

2.3.2. Proposal of a model to examine startup design and testing practices

A questionnaire composed of 80 questions is drawn up to interview entrepreneurs involved in real-world experimentation projects. Since our objective, through interviews, is to find out more the design and testing activities of startups, the questionnaire focused on the following topics:

(i) The profile of each company and the methods used to design their product and to perform tests;
(ii) The maturity level of their product before and after the tests;
(iii) A comparison between expected and obtained test results.

The first topic contains a set of questions to describe the use of design and testing methods. The degree of knowledge possessed by startups is then evaluated separately by method using a scale of 0 (no knowledge) to 5 (extensive knowledge of a given method) for four types of approaches: Lean Startup, Business Model Canvas, Design Thinking, and other approaches (for instance TRIZ, SWOT or Customer Development).

For the second topic the maturity level of the product is assessed by proposing a scale inspired by TRL (Technology Readiness Level) (Mankins, 1995), called Market Maturity Level (MML), which is better-suited to the case of entrepreneurial companies (see Table 3) and turns out to be more easily understandable by startups.

Table 3. Proposed Market Maturity Level (MML) Inspired by the TRL

MML	Description
MML_1: Concept	*Research project, basic outlines of the product or service*
MML_2: Development	*CAD designs, computation modules*
MML_3: Basic prototype	*Basic mock-up to be lab-tested*
MML_4: Semi-advanced prototype	*Tested and pre-validated prototype, industrial use cases and generated data*
MML_5: Pre-production	*Trustable, validated and verified solution to be industrialized*
MML_6: Industrialized but not commercialized	*Proved solution*
MML_7: Commercialized	*Available on the market and widely used by customers*

The MML value is declared by startup managers for two moments: before and after tests (*bMML* and *aMML*) in order to calculate the improvement in maturity for each project after experiments. It is worth recalling that these interviews take place at the end of the real-world experiments.

The third topic deals with what was expected before conducting experiments compared with what was obtained at the end. To perform this comparison, we propose the use of a set of quantitative *innovativeness* proofs called UNPC, for Usefulness, Newness, Profitability and Concept, proposed and validated by authors in various entrepreneurial and intrapreneurial contexts (Yannou, Farel, et al., 2016), and further detailed in Table 4.

Our first experience with outlining UNPC during interviews shows that these indicators are easy to understand for entrepreneurs. However, after conducting the first 10 interviews with startups, a mid-term appraisal of interviews showed that besides UNPC proofs, they also frequently mentioned the need for *networking* and *marketing-communication*. In other words, a startup is considered as successful by entrepreneurs once it has engaged enough stakeholder commitments to launch its business, rather than being strong enough in terms of UNPC proofs. For this reason, a fifth proof called *Stakeholder network* (*S*) is added to the UNPC proofs (now UNPCS) and the first 10 interviewed startups are re-interviewed based on this new grid as described in Table 4.

Table 4. UNPCS proofs to assess expectations and results of experiments

Proof Type	Definition
Usefulness (U)	Proof of Usefulness is related to covering or responding to people's unsolved or poorly-solved problems.
Newness (N)	Proof of Newness has two main components: real technological newness as perceived by users and customers, and real usage newness.
Profitability (P)	Expected economic profitability of a project for both startups and customers, that is the marginal profit for the startup and the total profit of ownership which can also be associated with willingness-to-pay for customers.
Concept (C)	Twofold: for customers, an innovation must function in expected usage situations. For startups, the industrial feasibility and the robustness of the product.
Stakeholder network (S)	Three main components: (i) need for financial fund raising, (ii) ability to build partnerships for industrialization and commercialization of the product, and (iii) ability to communicate and leverage the network effect and lobbying activities.

Each proof of the UNPCS set is scored from 0 to 5 (5 strongest proof). The value of each proof is declared by startups managers for two key times: before the experiment (expected, or *e*UNPCS) and after it (obtained, or *o*UNPCS).

To validate the declarative statements of the startups, the quantitative data collected is subsequently verified and validated by innovation experts supervising interviewed startups, and by officials of the City of Paris and the Parisian Urban Lab who are directly involved in experimentation projects.

2.4. Learnings from survey on 60 innovative startups

2.4.1. Design and testing practices of interviewed startups

After reviewing the profiles of the 60 interviewed startups, we identify a general attitude towards designing a value proposition among the startups, consisting in (i) having an initial idea of a solution, (ii) developing and testing a first prototype of the final solution, (iii) networking with stakeholders (basically to raise funds, and to produce and sell the product), and (iv) finally pivoting if the business idea does not work. This falls perfectly within effectual heuristics: not surprisingly, insofar as the interviewed entrepreneurs all have significant experience in entrepreneurship.

The interviewed startups all claim that they were familiar with and applied some methods and tools to manage their innovation, to be more efficient and so increase their likelihood of success. The Business Model Canvas (BMC) is the most popular method. The survey tells us that all interviewed startups have a very good knowledge of the BMC and their average degree of knowledge of the BMC is 82%. The degree of knowledge of other methods is: Lean Startup 80%, Design Thinking 46%, and other methods 22%. These percentages are calculated separately per method. Therefore, startups are all familiar with the somewhat complementary and inter-compatible notions of customer segmentation, value map, effectuation, validated learning, build-measure-learn loops and prototyping.

Regarding the maturity improvement of value offers, the minimum observed maturity level at which startups engage in such experiments is the semi-advanced functional prototype (or MML 4 see Table 3). This means that they participate in tests with an already fixed idea of their solution and a testable high-fidelity artefact that has already been tested internally. A comparison between the maturity level of the value proposition, before and after the experiment, indicates that only five companies out of 60 (or almost 8%) that declared some improvement in their maturity level. This shows that at a first sight, the improvement in the maturity level is not necessarily achieved by startups, nor is it even expected by them. The question now is: what do startups expect from experimentation projects and what are the results obtained?

The UNPCS proofs (see Table 4) are used as indicators to carry out quantitative comparisons between the expectations *before* and results obtained *after* experiments. Data collected on all 60 startups regarding expected and obtained UNPCS (*e*UNPCS and *o*UNPCS) are statistically analyzed. A Student *t*-test is used to compare two series *e*UNPCS and *o*UNPCS. Since these experiments are intended as an opportunity for startups to test and improve their product, the null statistical hypothesis is defined here as: "*all startup companies participate in real-world experiments to improve their product and service to enhance usefulness and value creation potential of the latter*". After running *t*-tests, the *p*-values obtained are presented in Table 5.

Table 5. Statistical *p*-values from a comparison between expected and obtained UNPCS

Proof of Usefulness (U)	Proof of Newness (N)	Proof of Profitability (P)	Proof of Concept (C)	Proof of Stakeholder network (S)
0.75*	0.58	0.03	0.06	0.02

*$p < .05$.

According to results of *t*-test, the most statistically significant *p*-value at the threshold of 0.05 is the Proof of Stakeholder network (S) which refutes the null hypothesis stated above. This result shows that experimentation is perceived by startup companies more as an opportunity for business networking rather than for improving the usefulness and the newness of an innovation. In other words, the most important objective of real-world experiments is seen as getting funding, building partnerships, leveraging the networking effect or lobbying activities to meet the right market and to become successful.

However, an *ex post* survey on the 60 interviewed startups showed that 27% of them (16 startup companies) have failed in less than five years of operation on average. These failed companies were all extensively focused on networking and lobbying activities in their experimentation projects, and more than 270,000 euros of public funds (or 13% of the two million euros devoted to 60 startups) were spent for their experimentation projects. It is therefore important to focus on such failures and to investigate their causes.

2.4.2. Failure analysis of innovative startups

Shepherd et al. define entrepreneurial failure as the "*termination of an initiative to create organizational value that has fallen short of its goals*" (Shepherd and Patzelt, 2017). The end-effects of such a failure are financial, social, emotional, or a combination of them. However, in any entrepreneurial failure the common end-effect remains wasted time, money and human resources (Ries, 2011). To avoid such a loss, we explore the underlying reasons for entrepreneurial failure when it is about design and testing a value offer.

Inspired by the terminology and processes of Failure Mode, Effects and Criticality Analyses (FMECA), we define a systematic process to trace back the underlying root causes of failure for the 16 failed startups out of the 60. The FMECA appear relevant in our case as they identify potential failure modes and causes to be removed for future improvements of startup ecosystems. Here, our FMECA process was a backward analysis of:

(a) "value offer failure end-effects" (implications),
(b) "failure modes" (how failure occurs),
(c) "underlying issues" (why there is failure), and
(d) "failure root causes" (origins of issues).

Once this process is built, each object of the FMECA is defined for the case of startups failure based on available information of the failure situations. All 16 startups that failed are contacted and brief questions are asked to understand why and how their

value offer failed to provide true value to customers and users. After collecting a first set of data, three innovation experts who possess extensive knowledge of the failed startups are questioned. Subsequently, once a first list of failure root causes are identified, their value is quantitatively estimated during problem-cause brainstorming sessions with the three experts. In parallel, relevant literature related to such failures is also studied.

In Figure 10, the failure end-effect (a) is concentrated into "*wasted time and other resources*" (for example financial, human or local urban resources). The observed failure modes (b) were either company shut-down (called here "*company failure*") or its radical pivot to a completely different business ("*product failure*"). These observed failure modes correspond to the *subjective* and *objective* perspectives of entrepreneurial failure (Jenkins and McKelvie, 2016).

The underlying issues of failure (c) are the first level of failure causes. We deliberately exclude those failure issues related to entrepreneurial know-how, social and interpersonal skills (such as problems in the entrepreneurial team or lack of eagerness) and focus only on issues related to the value offer of the startup and its business model. Based on a review of business studies dealing with the reasons for the failure of startup companies, such as (CB-Insights, 2014; Patel, 2015), six failure issues are selected as relevant according to the design, experimentation and business model of a startup company. These issues are: "*Being inflexible and not actively seeking/using customer feedbacks*", "*Getting outcompeted*", "*No market need*" (or building something that nobody wants), "*Not viable business model*" (or the lack of business model or plan), "*Pricing/cost issues*" (or the selling price or costs are too high), and "*User-unfriendly product*" (or the product is not easy to use). These six issues cover the failure issues observed among the 16 failed startups. The likelihood of occurrence of these issues is then scored from 0 to 5 (5 as the most recurrent issue) by three experts. The three most recurrent issues out of six are presented in Figure 10, for which the root causes must be identified.

Eight root causes of failures (d) are identified (see left side of Figure 10). These causes are related to the product development process from the early stages of the innovation process through prototyping and testing a solution, and finally to the product commercialization phase. The lack of use or misuse of tools and methods is considered as a key failure cause, as lack of guidance and structure directly affects the design and testing practices of companies (Cross and Roy, 1989).

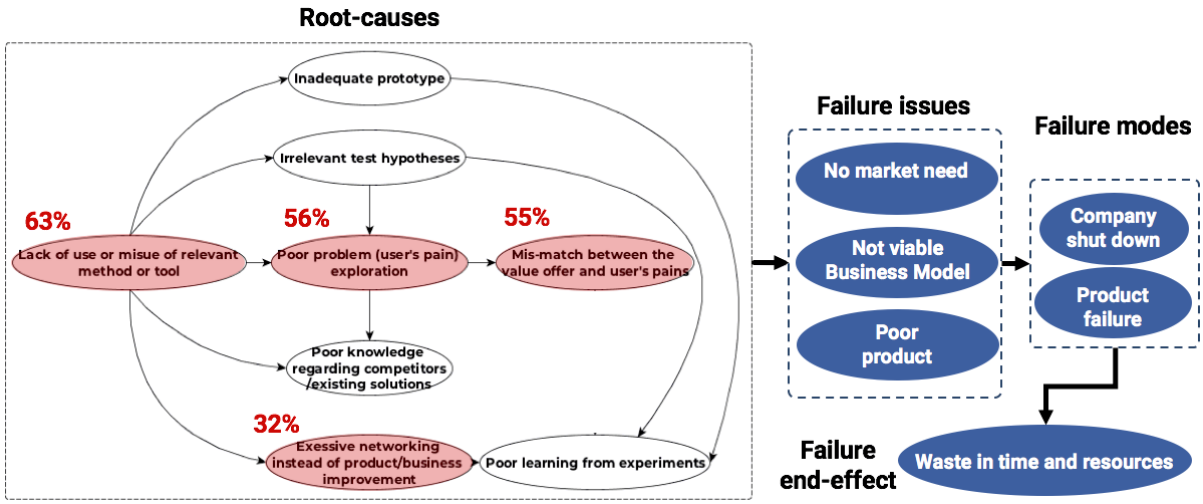


Figure 10. Root cause analyses of entrepreneurial failure

To incorporate the criticality analysis, the risk, generally reported as the Risk Priority Number (*RPN*), is evaluated by the product of likelihood of Occurrence (*O*), Detectability (*D*) and Severity (*Se*) of the identified root causes. Here, by taking Detectability (*D*) as constant for all root causes and for all failed startup companies, the *RPN* for a failed startup *i* is merely given by the product of *O* and *S*:

$$RPN_i = Se_i \times O_i. \quad (1)$$

The ranking scale of Se_i (severity) ranges from 0 to 1, with higher values representing more severe risks. The relative values of severity are identified based on the existing studies of reasons for startup failure (Patel, 2015; CB-Insights, 2014). The ranking scale of O_i ranges from 0 to 5, with 5 representing the most frequent failure cause. The value of O_i is then assessed for each failed startup company by three innovation experts. The average of *RPN* is calculated to rank root causes by their priority. This average is a percentage given for the first four root causes in the left side of Figure 10.

The FMECA technique in this case enable to show that "*excessive networking instead of product and service improvement*" is due to the lack of awareness of the opportunity to deploy a method or tool. Besides, a "*mismatch between the value offer and user's problems*" is due to a "*poor problem exploration*", because of "*lack of use or misuse of relevant methods and tools*". The latter is identified as the primary cause of failure by the three solicited experts, who possess extensive knowledge of the failed companies.

2.5. Data collection and validation process

The data used in this study are collected mainly from interviews with startup companies. The values for maturity level before and after experiments together with UNPCS before and after tests are declared by interviewed entrepreneurs for their own project. These data are then cross-checked and validated by innovation experts and other stakeholders involved in experimentation projects.

Regarding the qualitative and quantitative data collected for failure analyses, the lack of scientific study of the reasons for the failure of startups prompt us to use expert appraisal. For this purpose, problem-cause brainstorming sessions (two sessions of one hour each) and an evaluation heuristics session (one assessment session of two hours) are performed. In each session, three innovation experts take part (one from the Innovation Office of the City of Paris and two from Parisian Urban Lab) with extensive knowledge of failed projects. To make sure that the final results reflect reality, and that the experts' degree of subjectivity is reduced, we have contacted all 16 failed startup companies and briefly re-interviewed them. For these startups, the general final results made sense and represented a first type of study that differed from failure conferences or reports on reasons for failure of startups (CB-Insights, 2014; Patel, 2015), where entrepreneurs merely relate their experiences of failure without exploring the underlying reasons for it and their criticality. The results obtained from the failure analyses thus made sense.

2.6. Discussions

2.6.1. Significance and newness of the results obtained

Our survey on the practices of innovative startups show that popular methods and tools such as the Business Model Canvas (BMC) and the Lean Startup are undoubtedly useful and effective in most cases. However, in most cases they are not deployed by innovative startup at all, or startups do not fully leverage the potential of these methods.

In the first case, one may argue that the reason why methods and tools are not deployed is that their use might be counterproductive, since the short-term development cycles and limited resources of startups do not allow them to follow a structuring method. However, it is acknowledged that a method or a tool can significantly create a common language in a team and accelerate the innovation process (see for instance, (Eppler and Hoffmann, 2012; Osterwalder and Pigneur, 2010)). Moreover, methods and tools do not harm the innovation process of a startup, but reinforce it and contribute to a better organization of the startup and its action

plans in terms of innovation (see for instance, (Astebro, 2004)). The lack of deploying methods and tools is therefore related to lack of knowledge or education regarding their usefulness and positive contributions if they are correctly understood and implemented by startups.

In the second case, although startups may be very cognizant of popular methods and tools, they do not necessarily deploy them correctly in their design and testing processes. However, as (Ladd, 2016) mentioned: "*a method must be tailored and employed with reflection and constraints, not blind allegiance*". It is therefore important to help startups master the proper application of methods with more practical tools.

The framework of analysis proposed in this paper can be used to examine the practices of innovative startups in other contexts, insofar as it prescribes elements such as a structured questionnaire along with a set of metrics: these elements assist in monitoring startup design and testing processes by systematically questioning the maturity level of a startup value proposition and its test assumptions and expected results. To our knowledge, such a framework is new and can help decision-makers diagnose the design and testing in the context of innovative startups.

Our analyses on startup failures using the FMECA technique show that the "*lack of use or misuse of methods and tools*" can cause the "*poor problem exploration*" and thus a mismatch between the startup value proposition and market need (see Figure 10). We consider that this approach to analyzing causes of failure at the level of an entrepreneurial firm is new and differs from the current approaches. In prior studies the main failure reasons were identified as "*traditional business planning strategies*" (Ries, 2011), or "*lack of viable business model*" (Truong, 2016). However, these reasons have underlying root causes that arise from attitude of the startups and their use (or non-use) of practical tools or methods. Therefore, in our view, the existing literature has not yet provided sufficient studies to scientifically identify root causes of failure of startup from the perspective of startup's value offer.

2.6.2. Limitations

First, one may underline that the studied perimeter of this research consists in startups conducting real-world experiments in an urban area. This is indeed a specific situation of experimentation without necessarily focusing on other design activities of a startup, such as R&D planning, research and evaluation. The "design and testing practices" are thus reduced to field trials of prototypes in this study. Authors are aware of this limitation, but may emphasize again the importance of this topic in the studied perimeter.

Second, the quantitative data collection process needs to be improved with complementary sources. Employing semi-directive interviews and conducting focus sessions with experts can be questionable in terms of their relevance because of the subjectivity of participants. More structuring tools to conduct effective interviews and brainstorming are needed in this study.

Finally, further research and data are required to extend and validate the root causes of failure at both firm and individual levels: reasons for failure may also be related to the entrepreneur's personality and background and may influence the root causes at the firm level. However, this research focuses specifically on reasons for failure at the value offer level (related to decisions at the level of startups and their design and business development) which thus forms a further limitation as its link to other failure reasons is not mentioned.

2.7. Conclusion and perspectives

In this research, we seek not only to understand the design and testing practices of startups, but also to investigate the reasons why most startups fail, as their value offer is not a right fit to the market. To this end, we have carried out a survey on 60 innovative startups from different fields. Among these startups 75% of them are technology-oriented. These 60 startups have all conducted real-world experiments in the Paris area, in which multiple stakeholders were involved: 27% of the 60 studied startups failed in less than five years of operation on average.

As a first contribution, this paper proposes a new framework to examine not only the design and testing methods used by innovative startups, but also provides a set of quantitative indicators such as the level of maturity on the market (MML) and a set of innovativeness proofs to diagnose startups practices in terms of product development. By applying this framework to the case of 60 innovative startups, statistical analyses show that the main concern of startups in the real-world experiments is to leverage business networking and lobbying instead of improving the maturity of their value proposition.

The second contribution of this paper is a systematic analysis of the reasons for innovative startup failures. This analysis shows that the main reason at the value offer level among innovative startups is their lack of knowledge regarding end-users, caused by the misuse or the lack of use of the full potential of existing methods and tools.

Subsequent research will take a systematic problem exploration into consideration rather than insisting on directly developing a prototype and a business model. A useful problem is associated with important end-users' problems from existing solutions in

frequent usage situations. These unsolved or poorly-solved problems are called value buckets and are thoroughly measured by (Yannou, Cluzel, et al., 2016). Our future research work will focus on: (i) evaluating value buckets prior to the development of a BMC and conducting experiments, (ii) identifying relevant scenarios of experimentation, and (iii) planning testing activities of startups and identifying the optimal activities given the limited time and resources of startup companies.

Acknowledgement

The authors gratefully thank the meaningful help of 60 innovative startups as well as the following persons, who spent several hours with us in interviews and brainstorming sessions: F., Chabbert, A., Festal, A., Godard, and A., Coussy.

2.8. References

Astebro, T. (2004). Key success factors for technological entrepreneurs' R&D projects. *IEEE Transactions on Engineering Management, 51*(3), 314-321.

Aulet, B. (2013). *Disciplined entrepreneurship: 24 steps to a successful startup*: John Wiley & Sons. 1118720814.

Beaudouin-Lafon, M., and Mackay, W. (2003). Prototyping tools and techniques. *Human Computer Interaction-Development Process*, 122-142.

Beck, K. (2003). *Test-driven development: by example*: Addison-Wesley Professional. 0321146530.

Blank, S. (2013a). *The four steps to the epiphany: successful strategies for products that win*. New Jersey, United States: BookBaby. 0989200523.

Blank, S. (2013b). Why the lean start-up changes everything. *Harvard business review, 91*(5), 63-72.

CB-Insights. (2014). The top 20 reasons startups fail. *CB Insights*. Retrieved from: https://www.cbinsights.com/research/startup-failure-reasons-top/. Access date: July 2018.

Cross, N., and Roy, R. (1989). *Engineering design methods* (Vol. 4). New York, United States: Wiley.

Davis, A. M. (1992). Operational prototyping: A new development approach. *IEEE software, 9*(5), 70-78.

Dow, S. P., Glassco, A., Kass, J., Schwarz, M., Schwartz, D. L., and Klemmer, S. R. (2012). Parallel prototyping leads to better design results, more divergence, and increased self-efficacy *Design Thinking Research* (pp. 127-153): Springer.

Eppler, M. J., and Hoffmann, F. (2012). Does method matter? An experiment on collaborative business model idea generation in teams. *Innovation, 14*(3), 388-403.

Feinleib, D. (2011). *Why startups fail: and how yours can succeed*: Apress. 1430241403.

Fisher, R. A. (1937). *The design of experiments*: Oliver And Boyd; Edinburgh; London.

Furr, N. R., and Dyer, J. (2014). *The Innovator's Method: Bringing the Lean Startup Into Your Organization*: Harvard Business Press. 1625271468.

Hanshaw, N., and Osterwalder, A. (2015). The business model canvas: Why and how organizations around the world adopt it (A field report from Strategyzer). Retrieved from: https://blog.strategyzer.com/posts/2015/2/9/why-and-how-organizations-around-the-world-apply-the-business-model-canvas. Access date: July 2018.

Jenkins, A., and McKelvie, A. (2016). What is entrepreneurial failure? Implications for future research. *International Small Business Journal, 34*(2), 176-188.

Kerr, W. R., Nanda, R., and Rhodes-Kropf, M. (2014). Entrepreneurship as experimentation. *The Journal of Economic Perspectives, 28*(3), 25-48.

Kim, W. C., and Mauborgne, R. (2014). *Blue ocean strategy: how to create uncontested market space and make the competition irrelevant*. Massachusetts, United States.

Ladd, T. (2016). The Limits of the Lean Startup Method. *Entrepreneurship.* Retrieved from: https://hbr.org/2016/03/the-limits-of-the-lean-startup-method. Access date: July 2018.

Mankins, J. C. (1995). *Technology readiness levels*. Retrieved from

McDonald, J. A., Ryall, C. J., and Wimpenny, D. I. (2001). *Rapid prototyping casebook*: John Wiley & Sons. 1860580769.

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey, United States: Wiley. 9780470901038.

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., and Papadakos, T. (2015). *Value Proposition Design: How to Create Products and Services Customers Want*. New Jersey, United States: Wiley. 9781118968055.

Pahl, G., and Beitz, W. (2013). *Engineering design: a systematic approach*: Springer Science & Business Media. 1447135814.

Patel, N. (2015). 90% Of Startups Fail: Here's What You Need To Know About The 10%. *Forbes. com.* Retrieved from: https://www.forbes.com/sites/neilpatel/2015/01/16/90-of-startups-will-fail-

heres-what-you-need-to-know-about-the-10/ - 4da901f26679. Access date: July 2018.

Porter, M. E. (2008a). *Competitive advantage: Creating and sustaining superior performance*: Simon and Schuster. 1416595848.

Porter, M. E. (2008b). The five competitive forces that shape strategy. *Harvard business review, 86*(1), 25-40.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

Sarasvathy, S. D. (2001). Causation and effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency. *Academy of management Review, 26*(2), 243-263.

Sarasvathy, S. D. (2009). *Effectuation: Elements of entrepreneurial expertise*: Edward Elgar Publishing. 1848440197.

Shepherd, D. A., Douglas, E. J., and Shanley, M. (2000). New venture survival: Ignorance, external shocks, and risk reduction strategies. *Journal of business venturing, 15*(5), 393-410.

Shepherd, D. A., and Patzelt, H. (2017). Researching Entrepreneurial Failures *Trailblazing in Entrepreneurship: Creating New Paths for Understanding the Field* (pp. 63-102). Cham: Springer International Publishing.

Thomke, S. (2014). Accelerating Learning by Experimentation. In O. Gassmann and F. Schweitzer (Eds.), *Management of the Fuzzy Front End of Innovation* (pp. 125-140). Cham: Springer International Publishing.

Thomke, S., and Manzi, J. (2014). The discipline of business experimentation. *Harvard business review, 92*(17), 17.

Thomke, S. H. (2003). *Experimentation matters: unlocking the potential of new technologies for innovation*: Harvard Business Press. 1578517508.

Truong, A. (2016). After analyzing 200 founders' postmortems, researchers say these are the reasons startups fail. *Lesson Learned – QUARTZ*. Retrieved from: https://qz.com/682517/after-analyzing-200-founders-postmortems-researchers-say-these-are-the-reasons-startups-fail/. Access date: May 2018.

Ullman, D. G. (1992). *The mechanical design process* (Vol. 2). New York, United States: McGraw-Hill. 9780073398266.

Ulrich, K., and Eppinger, S. (2015). *Product design and development*: McGraw-Hill Higher Education. 1259297136.

Unger, D., and Eppinger, S. (2011). Improving product development process design: a method for managing information flows, risks, and iterations. *Journal of Engineering Design, 22*(10), 689-699.

Womack, J. P., and Jones, D. T. (1997). Lean thinking—banish waste and create wealth in your corporation. *Journal of the Operational Research Society, 48*(11), 1148-1148.

Wu, J. J., and Atkinson, R. (2017, November 2017). How Technology-Based Start-Ups Support US Economic Growth. Retrieved from: https:// http://www2.itif.org/2017-technology-based-start-ups.pdf. Access date: July 2018.

Yannou, B., Cluzel, F., and Farel, R. (2016). Capturing the relevant problems leading to pain and usage driven innovations: the DSM Value Bucket algorithm. *Concurrent Engineering: Research and Applications*, 1 - 16. doi:10.1177/1063293x16666311

Yannou, B., Farel, R., Cluzel, F., Bekhradi, A., and Zimmer, B. (2016). The UNPC innovativeness set of indicators for idea or project selection and maturation in healthcare. *International Journal of Design Creativity and Innovation, 5*(3-4), 205-221. doi:10.1080/21650349.2016.1161562

Research questions

We focused in Chapter 1 on the urban area and urban stakeholders involved in innovative projects. The investigations in chapter 1 demonstrated that there is need for a systematic selection of urban-centered innovations (i.e., an innovative products and services designed by city-based startups) before conducting real-world experiments. In addition, these investigations confirmed that an in-depth understanding of end-user's problems from the early stages of the innovation process enables startups to create useful products and services.

Chapter 2 made a focus on startup companies and their value proposition. Through investigations on design and testing practices of 60 innovative startups, this chapter showed that most of these startups failed due to a poor knowledge of end-users' problems, arising from the misuse or lack of use of existing methods and tools. Therefore, it is worthwhile to conduct further research with the purpose of providing practical methods and tools to enable startups offering useful innovations.

Based on the investigations reported in chapters 1 and 2, three research questions are defined. These questions deal with business and technological perspectives in the context of startups. The three research questions of this research are:

(1) How to ensure that the startup's value offer, described in a Business Model Canvas (BMC), is significant and effective before the completion of the BMC and the launch of experiments?

This question is formulated for the following reasons:

- Despite the practicality of the BMC, our survey study shows that there is a general lack of awareness of entrepreneurs to explore systematically the innovation problem to be solved. Their value offer lacks usefulness and strength.
- The informal and graphical features of the BMC make it convenient for innovative startups to outline their business models. However, its visual nature encourages entrepreneurs to initiate their innovative project by expressing business model assumptions without verifying their relevance.
- Despite the effectiveness of the BMC to structure and describe a business model, it remains merely qualitative. It is therefore difficult to quantitatively estimate the relevance of the business model assumptions and ideas.

Indeed, the first research question tackles the issue of business modeling in the context of technology-based startups. However, to deal with both business and technological perspectives in this context, two other research questions are formulated in the following.

(2) What are the most promising markets and the technology properties that a technology-oriented innovative startup should target through experiments, with limited resources and time?

The results of the survey study presented in chapter 2 showed that: approaches such as Lean Startup and their related techniques have helped significantly change the traditional startup mindset and practices. However, these approaches advocate merely loop-based testing of an innovative product-service without systematically providing decision supports regarding the markets and the technology properties to be targeted and improved through experiments. Indeed, when one must structure experiments to make mature an innovative value offer, it is crucial to identify the market gap and the aspects of the technology to be improved through tests.

Moreover, as the time as well as other resources of a startup are limited, conducting random tests and pivots can lead to important waste and failure. It is therefore worthwhile to formulate this second research question that focuses on structuring experiments of a technology-oriented innovative startup.

(3) How to identify the most cost-effective R&D activities and their short-term planning that enable a technology-oriented innovative startup to improve the maturity of its technology and successfully meet the promising markets?

Given the scarcity of resources in startups, their investment needs to be monitored and carefully steered towards worthy R&D activities. Our investigations showed that the existing methods and tools in technology roadmapping and forecasting as well as in innovative entrepreneurship fail at providing quantitative decision supports to specify and plan cost-effective R&D activities of technology-based startups. Therefore, investments of a technology-oriented innovative startup remain rather unplanned and follow the intuition or sporadic market researches of entrepreneurs. In this context, there is need for systematically collecting quantitative data on market and the technology to specify optimized R&D activities that allow setting up relevant technology maturation roadmaps.

In the next part of this PhD, we provide answers to the above-mentioned research questions by dedicating a chapter to each question. The three following chapters

correspond to the fourth and fifth steps of our research flow as described in the General Introduction (see Figure 1)

PART II. CONTRIBUTIONS

In this part, we present the contributions of this dissertation through three chapters. Each chapter aims at answering to one of the identified research questions. A methodological proposition is the contribution of each chapter.

Chapter 3 presents a more rational use of the popular tool of Business Model Canvas. Once we have discussed the business perspectives of technology-oriented innovative startups, we then move on to both business and technological aspects in the following chapters.

Subsequently, chapter 4 deals with structuring the experimentation process of an innovative startup to specify and delineate relevant experiments of the technology for its promising markets.

Finally, chapter 5 provides more quantitative indicators and techniques to identify a set of optimal R&D (here testing) activities that enable the startup to plan more effectively its activities and to allocate better its budget and time.

Chapter 3. Paper #3: Capturing relevant innovation problems for a more rational use of the Business Model Canvas (BMC)

This paper is submitted to the Journal of Business Research in November 2018, under the following reference:

- Bekhradi, A, Yannou, B., and Cluzel, F. (2018). Capturing relevant innovation problems for a more rational use of the Business Model Canvas (BMC), *Submitted to Journal of Business Research*.

The conference paper which provides the basis of this paper is:

- Bekhradi, A., Yannou, B., and Cluzel, F. (2016). Importance of problem setting before developing a business model canvas. 14th International Design Conference - DESIGN 2016, Dubrovnik, Croatia. May 2016.

Foreword

The previous part underlined the importance of designing as well as testing methods and tools, and concluded that their misuse or lack of use can lead to failure in the context of technology-oriented innovative startups.

Following this conclusion, the rest of this dissertation aims at providing new methods and tools to address the identified issue.

To do so, we observe in this chapter that a premature use of the Business Model Canvas (BMC), which is one of the most popular tools among startups, often leads to important waste and failure.

Therefore, the aim of this chapter is to provide a new method to improve the use of the BMC before conducting experiments. This method is a hybridization of the BMC and the Radical Innovation Design® (RID) methodology.

Abstract: The Business Model Canvas (BMC) is one of the most popular and practical tools of innovative entrepreneurship. Most often, startups use the BMC to visually present and communicate their ideas, assumptions, and explain or justify the experiments that they conduct. However, a premature use of the BMC can lead to important wastes and failure, mainly in technology-based startups. This is mostly due to a primary poor and unjustified product-service for some customer segments, which is in turn due to a lack of relevance of the innovation problem to be solved. The main contribution of this paper is a method called BMC-RID (for Radical Innovation Design®) which makes the use of the BMC more rational. The RID methodology provides a relevant set of tools that can be combined with the BMC, not only to quantify a set of useful problems, but also to measure and monitor the relevance of ideas and assumptions emerging along the BMC development, prior to the launch of experiments. This paper offers a set of three practical guidelines for practitioners.

Keywords: Business Model Canvas, problem exploration, front end of innovation, Radical Innovation Design®, experimentation.

3.1. Introduction

"*The reason why succeeding at innovation has seemed so unpredictable—is that researchers to date haven't provided a body of theory that is valid and reliable enough to give innovators a solid sense of whether there is "oil down there" before they start drilling*" (Christensen, 2013). In the context of innovative startups, the mainstream mindset consists in building quick and dirty prototypes and testing them to *see whether there is oil down there or not*. However, this mindset often leads to excessive use of resources, and ultimately to the failure of the startup. This paper is about providing quantitative evidences to ensure that there is "*oil* [or value] *down there*" to be exploited before starting to drill or to experiment.

Based on the *oil drilling* metaphor, the concept of business model (see, e.g., (Osterwalder and Pigneur, 2010; Zott et al., 2011; Trimi and Berbegal-Mirabent, 2012; Massa and Tucci, 2013; Teece, 2010)) is regarded more as an *exploitation* tool rather than an *exploration* one. Given that both exploration and exploitation approaches are useful to help entrepreneurs make business and experimentation decisions, we reflect in this paper on how to combine them in order to make the whole process of value creation more effective.

A particular attention is devoted to the well-known approach of business modeling called Business Model Canvas (BMC) (Osterwalder and Pigneur, 2010). The latter is

considered as one of the most popular[4] business modeling tools among professionals and academics.

The BMC is a powerful business modeling template that illustrates business functions in a visual, easy-to-understand and easy-to-share fashion. It creates a common language between the design team members as well as between the company and external stakeholders (e.g., investors and suppliers). This tool is therefore relevant and useful to describe and to manage a business through the nine building blocks of its canvas. Besides, the ease of use of the BMC and its visual features makes it convenient to be abundantly used by innovative startups.

One may observe that technology-based innovative startups use even more often the BMC due to their limited time and pressing need to run experiments. However, the simplicity of the BMC template can be misleading as this template can be filled without necessarily verifying the relevance of the value offer nor the significance of customer/user segments. Subsequently, based on the completed canvas, startups run experiments to see whether the initial business model assumptions are relevant or not. As such, the exploration task prior to exploitation is neglected. This can thus make the use of the BMC counterproductive or can even lead to failure (see examples further in this paper).

Despite the introduction of complementary concepts and templates by (Osterwalder et al., 2015) as well as the extensions of the BMC template (see for instance Lean Canvas (Maurya, 2012)), there is still a lack of quantitative indicators to elicit and structure customer problems and to come up with strong value propositions.

Based on these observations and the early-use of the BMC, it is legitimate to ask: **how to ensure that the startup's value offer, described in a Business Model Canvas (BMC), is strong and effective before the completion of BMC and the launch of experiments?**

With this question as its principal driver, this paper has a two-fold objective: first, fostering a more rational use of the BMC through a systematic exploration of unsolved or poorly-solved problems at the front end of innovation; and second, providing a quantitative technique to assess the relevance of assumptions and ideas expressed in a BMC allowing to conduct for more purposeful and effective experiments.

The proposed technique fills not only the void of systematic problem exploration when one uses the BMC, but also the lack of quantitative proofs to measure and monitor the relevance of experiments to be conducted once the BMC is filled.

[4] One may claim that the BMC is probably *the* most popular tool of entrepreneurs. The Strategyzer blog indicates that the BMC along with their other tools are used by more than five million people, most of them being entrepreneurs (Hanshaw and Osterwalder, 2015).

Through a set of workshops with an innovative technology-based startup and with a group of students in an innovation course, the proposed technique has been tested and enabled participants better evaluating the relevance of their assumptions/ideas, and also strengthening the significance of their experiments.

This paper is structured as follows. In Section 3.2, the BMC, some of its variations as well as their shortcomings are presented. Section 3.3 demonstrates, through examples of technology-oriented innovative startups, that a premature use of the BMC can lead to failure. Further, in Section 3.4 we introduce a problem setting technique than can be combined with the BMC. Then, Section 3.5 presents a set of proofs that enable measuring and monitoring the relevance of business model assumptions and ideas. Based on Sections 3.4 and 3.5, Section 3.6 summarizes a set of practical guidelines for startups.

3.2. Background

In recent years, the concept of business model has attracted the attention of managers and academics alike. (Zott et al., 2011) noted a dramatic increase in the use of the term business model between 1955 and 2010. (Teece, 2010) outlines that a business model is a conceptual rather than financial model of a business. It encompasses "*management's hypothesis about what customers want, how they want it, and how the enterprise can organize to best meet those needs, get paid for doing so, and make a profit*". In this paper, we focus on the Business Model Canvas which is defined as "*the rationale of how an organization creates, delivers and captures value*" (Osterwalder and Pigneur, 2010).

3.2.1. Business Model Canvas (BMC)

The BMC, as illustrated in Figure 11, can capture the big picture of a business through nine interconnected components or blocks (i.e., Customer Segments (CS), Value Proposition (VP), Channels (C), Customer Relationship (CR), Revenue Streams (RS), Key Activities (KA), Key Resources (KR), Key Partnerships (KP), and Cost Structure (CT)). Each block contains a set of questions to validate the business model and corroborate its internal strength. In general, the key ideas and assumptions are written or depicted on Post-It® notes over the blocks of the BMC.

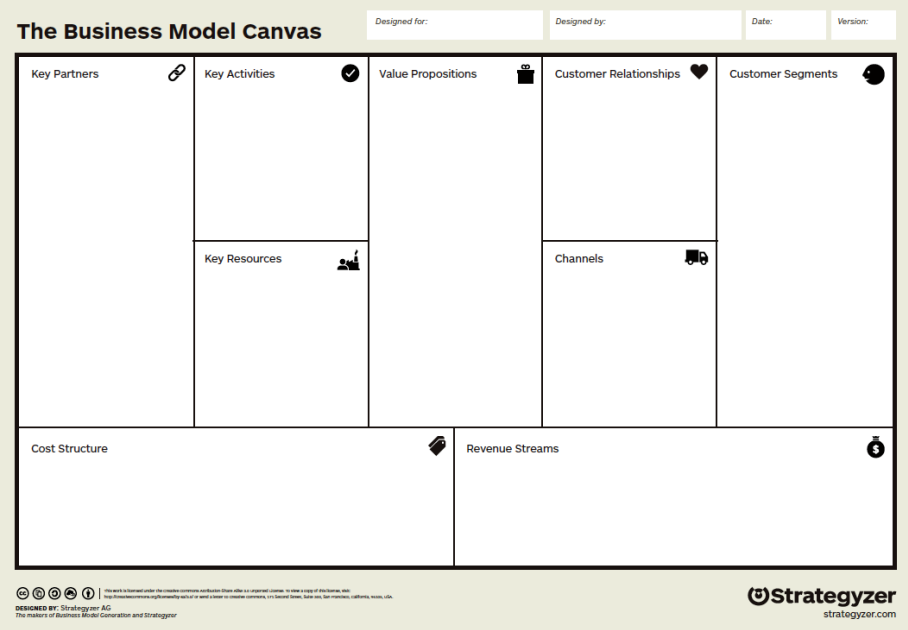


Figure 11. Business Model Canvas (Osterwalder and Pigneur, 2010)

As a powerful visual thinking tool, the BMC can facilitate discussion and debate with users and other stakeholders comparing to Porter's five forces model (Porter, 1985) or SWOT analysis (standing for Strengths, Weaknesses, Opportunities and Threats). The BMC provides therefore a simple and intuitive tool that can be developed quickly and applied to iterate and verify the company's business model assumptions. This makes the BMC hands-on and attractive for entrepreneurs.

3.2.2. BMC and entrepreneurship

(Trimi and Berbegal-Mirabent, 2012) explain that the BMC can help entrepreneurs in four ways. First, the visual template enables the exercise of constant reflection. Second, it allows entrepreneurs, customers, and other stakeholders understanding how the business articulates its different components. Third, it forces entrepreneurs to simultaneously consider each of the elements of the business individually but also as a whole. Fourth, the use of a visual support contributes to increase business creativity and innovation. The canvas incorporates the design thinking methodology which encourages creative developments based on the needs and desires of customers.

A fifth way that the canvas can help entrepreneurs is its ability to foster experimentation. Authors showed that the BMC can be used to extract test hypotheses before launching experiments along with an organized test process (Osterwalder et al., 2015).

As (Trimi and Berbegal-Mirabent, 2012) indicated, the usefulness of the BMC and its popularity among entrepreneurs have led to new improvements and variants of this tool.

3.2.3. Variants of the BMC

Some of the adaptations of the BMC merely suggest additional blocks. For instance, Hulme from IDEO has proposed a Business Model Framework (BMF) which consists of two additional complementary blocks that consider the planning and assessment of growth and competitive advantage of the firm (Trimi and Berbegal-Mirabent, 2012). Another example is called the model*H* (Riley, 2014) which is a complex business model canvas designed specifically for healthcare containing seven more blocks than the classical canvas.

Other adaptations go beyond merely adding new components or renaming the existing ones. To support creativity and innovation towards more sustainable business models, (Joyce and Paquin, 2016) have proposed the Triple Layered Business Model Canvas (TLBMC) as a new design tool that structures sustainability issues in business model innovation.

To better encompass the problem in the business model, Maurya (Maurya, 2012) has transformed the classical canvas to more actionable and entrepreneur-focused tool. This new tool is called the Lean Canvas which focuses on problems, solutions, key metrics and competitive advantages. This model omits four existing blocks of the BMC in an attempt to improve it. Maurya found that several businesses do fail applying a lot of effort, financial resources and time to build the wrong product. It is therefore vital to understand the problem first in relation to the customer segments. The problems are then listed from their priority perspective in this block. The key metrics include key measures that are used to monitor performance and they are identified on a case-by-case basis by the startup.

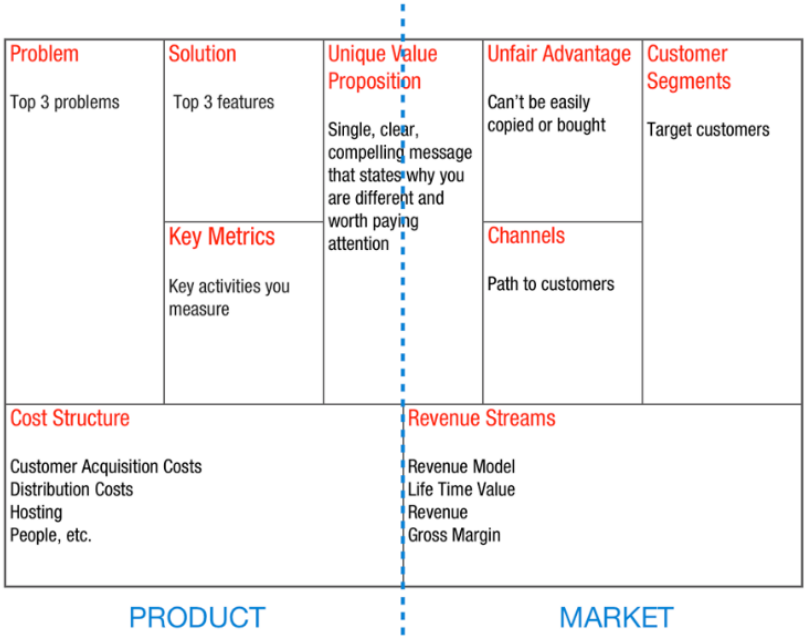


Figure 12. The Lean Canvas

The Customer Segments (CS) and Value Proposition (VP) represent the central pillars of any business canvas around which other blocks evolve. These two blocks determine the core behaviors and activities of a given business and its targets. Following the increasing demand of practitioners (Osterwalder, 2014), the authors of the Business Model Generation book have proposed complementary canvases (Osterwalder et al., 2015) to thoroughly diagnose and test the core of a business model.

3.2.4. Value Proposition Design (VPD)

(Osterwalder et al., 2015) refined the mapping of Value Proposition and Customer Segments and the fit or matching between these two (see Figure 13). A Customer Profile is defined by three components: *pains*, *gains* and *jobs-to-be-done*. A Value Map is made of *pain alleviators*, *gain creators* and *job contributors*.

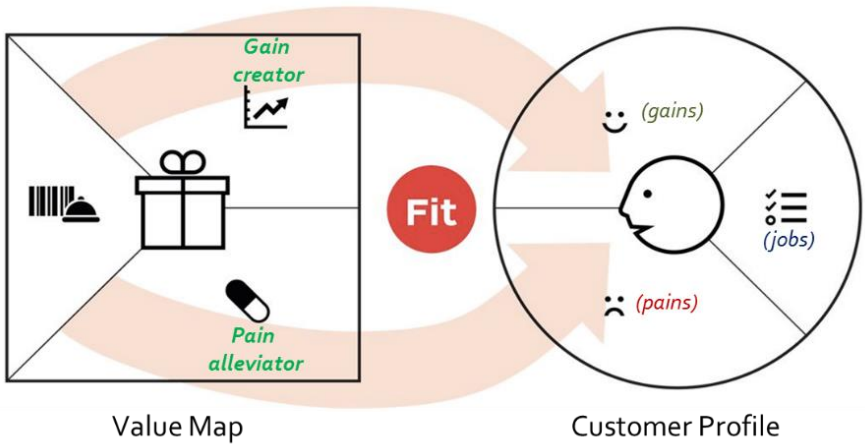


Figure 13. Designing the fit between a customer profile and value proposition (Osterwalder et al., 2015)

The VPD method proposes a set of tools and techniques to organize information about what customers want in a simple way that makes the patterns of value creation easily visible. Besides, it includes a three-stage testing process: testing the Customer Profile, testing the Value Map and finally the BMC.

3.2.5. Some lacks in the BMC and its variants

It is obvious that the BMC, its variant as well as the Value Proposition Design tools are relevant to develop, manage and test a business in a startup. However, despite the practicality of these tools, they are not without some limitations:

- They do not enable to systematically explore problems at the front end of innovation, i.e., the earliest moment before entering a formal product development process, where innovators try to discover and assess the relevance of innovation opportunities (or growth territories). Besides, the importance of the problem to be solved is not quantified.
- The significance of assumptions and the relevance of ideas expressed in different blocks of the BMC are not measured and monitored. This can lead to random and costly trial and error.

The identified limitations are consistent with the major issues of business models identified by (Shafer et al., 2005): (i) flawed assumptions underlying the core logic of the business, (ii) limitations in the strategic choices considered, (iii) misunderstandings about the value creation and value capture, and (iv) flawed assumptions about the value network.

Even though Shafer et al. mentioned these issues before the emergence of the BMC from 2010, it appears that these issues are persisting. To verify them, examples of startups using the BMC are presented in the next section.

3.3. Premature use or misuse of the BMC can lead to important wastes and failures

First, we will take two examples of startups that used the BMC from early design stages to illustrate and experiment their business functions. These examples are derived from our observations over the real-life experimentation projects conducted by innovative startups in Paris, France (see (Bekhradi et al., 2018a)).

The first startup produced a smart image/voice recognition box (see Figure 14) which aimed at creating not only social links between elderly people living in a retirement institute, but also to stimulate cognitive functions in order to prevent Alzheimer disease. The box worked with either RFID-based card games that contain an information (e.g., a quiz or a song), or images of the elderly's family or friend that were recognized by the box and phoned via a landline. In addition, the box enabled the coordination between healthcare assistants and detects falls and physical abnormal postures.

Figure 14. Image/voice recognition box for creating social links for the elderly

The startup, established by experienced occupational therapists, won three national innovation awards since its creation for a total of five hundred thousand euros of seed capital. This shows that the public and private funders were convinced by the potential of this business, clearly presented through a Business Model Canvas. However, once the finalized prototype was brought to real-life tests in retirement homes of the City of Paris, an unfortunate situation occurred: only 2 elderlies among 50 residents of the retirement home were keen to test the solution, because they were illiterate. Besides, the usefulness of the solution to prevent Alzheimer was very poor as it constantly required aiding people to explain many times to Alzheimer patients why the box was there and what it was made for. Few months after this failed experimentation, the company was shut down. Even though, at the end of the startup's life cycle, the founder

has developed several new features, important effort yet was devoted to the networking and lobbying instead of exploring the elderly's problems and pains.

The second example is the case of a startup that produced modular street bike lockers. Users can lock their bikes in vertical position (see Figure 15). The whole locker can be easily installed on the public spaces as the modules can be interlocked together with little effort. In this case, the startup had defined and completed its Business Model Canvas without directly integrating the needs, constraints, problems and pains experienced by its customers (here City's department of Streets and Transportation) and its end-users (i.e., urban bike riders). Once the finalized prototype was arrived at the test field some dysfunctions and problems were revealed. First, it was not practical for most users in some narrow sidewalks to hold their bikes vertically to fit them in the boxes. Second, the black body of the box was perceived as too dark by users. Therefore, the company had to adjust these problems and reproduce another prototype with an arm helping users to rise their bikes, and also replaced the body with transparent plated. This was costly and time-consuming, and finally not satisfactory for the City.

Figure 15. Urban vertical bike lockers

The studied examples of startups show clearly that the problem exploration is not systematically carried out when they have used the BMC. Besides, the nine blocks of the canvas were filled without necessarily justifying the relevance of each idea/assumption (written on Post-it® notes) as they were meant to be tested anyway. However, adopting such approach caused important wastes and failures after conducting experiments.

Based on the identified gaps with respect to the BMC literature and practices of startups, the subsequent two sections deal with the issues of: ensuring that the problem targeted by the BMC is worth of further experimentation, and validate the significance of other assumptions expressed in all the nine blocks of the BMC.

3.4. Importance of exploring a useful problem prior to the development of the BMC

(Spradlin, 2016) explains that "*… most companies aren't sufficiently rigorous in defining the problems they're attempting to solve and articulating why those issues are important. Without that rigor, organizations miss opportunities, waste resources, and end up pursuing innovation initiatives that aren't aligned with their strategies.*"

The problem exploration is an activity that not only involves problem finding, but also in-depth investigation for underlying causes for the problem (Schwenk and Thomas, 1983). Although, beyond the BMC, there are methods and tools to undertake the problem exploration (such as Design Thinking (Brown, 2009), Lean Startup (Ries, 2011), fishbone diagrams (Ishikawa, 1976) or TRIZ (Savransky, 2000; Souchkov, 2010)), startups still lack of rigor in systematic problem exploration prior to implementing a BMC.

To better illustrate this, we will focus on the case of a technology-oriented innovative startup that was launched by two Stanford engineering students who had the idea of building an autonomous lawnmower for golf courses (Blank, 2014). They first started to fill a BMC (see Figure 16) and were convinced that the customer segment to target was the owners of green spaces such as golf courses. Indeed, they had this intuition that their platform technology could have been applied to golf courses because of its precision and other differentiating features.

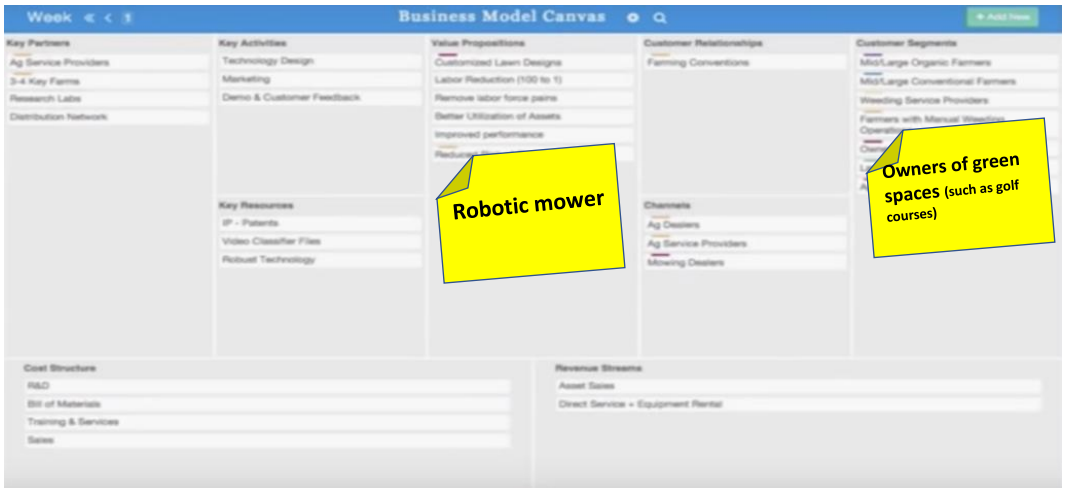


Figure 16. First BMC developed by Stanford student working on the autonomous mower project (see (Blank, 2018))

Before launching real-life experiments, they decided to "*get out of the building*" to observe end-users and their problems/needs. After a first round of exploration, they

have found out that a robotic mower is not needed by the owners of commercial green fields. Then, they explored problems related to the main activity or application of their technology, i.e., detecting weeds and cutting precision. A broader exploration therefore enabled them to realize that in the case lettuce thinning there are important problems and pains that are not addressed by the existing solutions. Thinning lettuce fields is a painful and tough task for farmers who, most often, hire illegal workers to accomplish this task. Based on the identification of this painful problem, the value proposition called Blue River Technology have managed nine months later to raise more than three million dollars in venture funding (Blank, 2013). Few years later, Deere & Company invested $305 million to fully acquire Blue River Technology.

The inspiring example of Blue River Technology demonstrates that even in the case where the entrepreneurial team was perfectly able to fill in the BMC, it had to quickly switch or pivot to another value proposition idea following its problem exploration at the front end of innovation.

To emphasize the importance of systematic problem exploration when one uses the BMC, it is not trivial to combine the use of a rigorous and practical problem setting tool with the BMC.

Several methods and tools exist to monitor the problem exploration phase. However, as mentioned by (Wedell-Wedellsborg, 2017) most of them are not used by startups because of their 'over-engineering' (for instance in the case of TRIZ and QFD (Aungst et al., 2003)) and thoroughness which make them time-consuming in the context of startups with limited time and resources. Entrepreneurial approaches, such as Design Thinking, Lean Startup, and Disciplined Entrepreneurship (Aulet, 2013), provide useful guidelines, but they fail at offering quantitative and tangible proofs to problem exploration.

The approach that can provide such practical and quantitative tool is the Radical Innovation Design® Methodology (RID) (Yannou et al., 2013). This methodology follows a need seeker innovation strategy (Jaruzelski et al., 2016) as it enables developing new products, services and business models based on *"superior end-user understanding"* and enable companies to seek out "*both articulated and unarticulated needs"*. RID indicates that the sporadic problem setting process [of startup] can be rigorously structured and lead to the identification of a worthy problems (called *value buckets*) for which existing design solutions are not effective in frequent usage situations. This falls within the scope of the Blue Ocean marketing strategy (Kim W.C. and Mauborgne, 2005), where a radically innovative solution can be differentiated in terms of essential value creation compared to the existing design solutions. Thus, the RID methodology puts forward a more substantial problem exploration process at the front end of innovation. The development of business functions appears in later design

stages of the RID process once the problem to be solved is well defined. For these reasons, problem exploration principles and tools of RID can be combined with the BMC.

The DSM-Value Bucket (DSM-VB) algorithm (Lamé et al., 2017; Yannou, Cluzel, et al., 2016) of the RID methodology highlights "*combinations of important problems/pains occurring during characteristic usage situations and for which existing solutions are generally neither useful nor efficient*" (Yannou, 2015). The DSM-VB is a set of three dependent matrices that can be reasonably used by a startup as the data feeding is not a complex task and does not require a particular skill.

DSM-VB matrices (as depicted in Figure 17) is an algorithm which links *usage situations* with *problems* and with *existing design solutions* (commercial solutions or patents). In a nutshell, this DSM-VB computes the difference between the unsolved or poorly-solved problems of users (matrix *A*) from those that are already addressed by the existing solutions (matrix *C* × *B*).

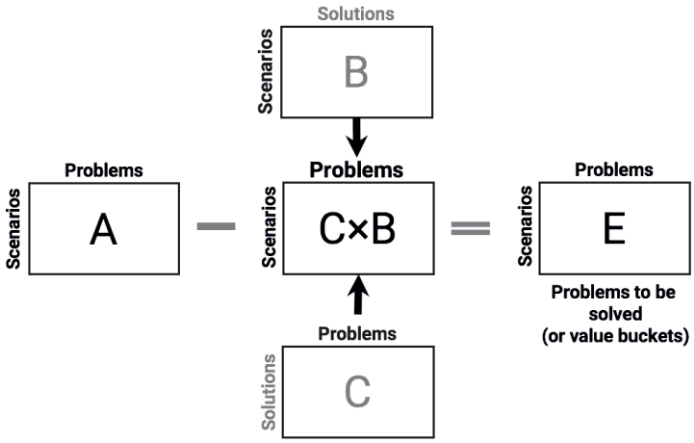


Figure 17. Data flow of the DSM-VB algorithm

In this algorithm, matrix A expresses to what extent people are subjected to problems/pains in different usage situations. Next, existing design solutions are identified and their ability to cope with problems (matrix B) and covering usage situations (matrix C) is quantified. Multiplying matrices B and C calculates the likelihood for the existing solutions to satisfactorily answer problems in usage situations. Subtracting this matrix (i.e., C × B) from matrix A results in a final "value buckets" matrix, highlighting which problem is worthy of being addressed in terms both of usefulness creation for users and competitive innovation opportunity.

The identified value buckets articulate legitimate and prioritized innovation problems that can further feed the Value Proposition and Customer Segments blocks of the BMC. However, given that most often more than one value bucket is identified, it is

necessary to make a choice among them and/or prioritize them. In the RID methodology, the prioritized subset of value buckets (called an *ambition perimeter*) is defined by the project team. This ambition perimeter is a consistent set of value buckets that includes: a subset of relevant value buckets as (problems × usage situations), other value buckets currently covered by existing solutions but that consumers consider as "*must have*" (based on a Kano Analysis for instance), and also those priority value buckets compatible with offer portfolio of the company.

In summary, to undertake a systematic problem exploration prior to the application of the BMC, the DSM-VB algorithm and the perimeter of ambition principle of the RID methodology make a structured contribution. A first hybridization of RID and the BMC can be summarized as the following process, as depicted in Figure 18: (1) using the DSM-VB algorithm to quantify a set of value buckets, (2) selecting and prioritizing of the value buckets in an ambition perimeter, and (3) starting to use the BMC from the Customer Segments and Value Proposition blocks and based on the identified ambition perimeter.

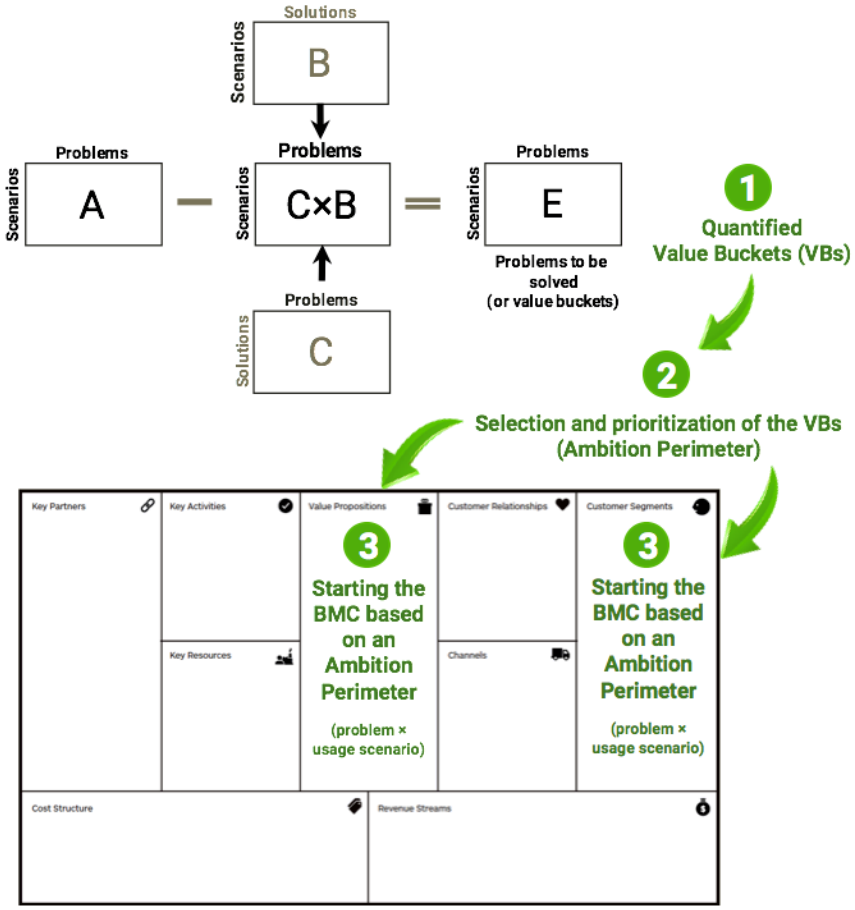


Figure 18. Rigorous problem exploration prior to the development of the BMC

The identified value buckets provide a set of pre-validated innovation problems to be further exploited and experimented with the use of the BMC. Subsequently, when the

business model assumptions and ideas are generated there is need to measure their relevance.

3.5. Measuring and monitoring the relevance of business model assumptions and ideas

IDEO suggests that "*when you sketch out a business model with the Business Model Canvas you actually make assumptions about desirability, feasibility, and viability* [and adaptability]" (IDEO, 2015) (see Figure 19).

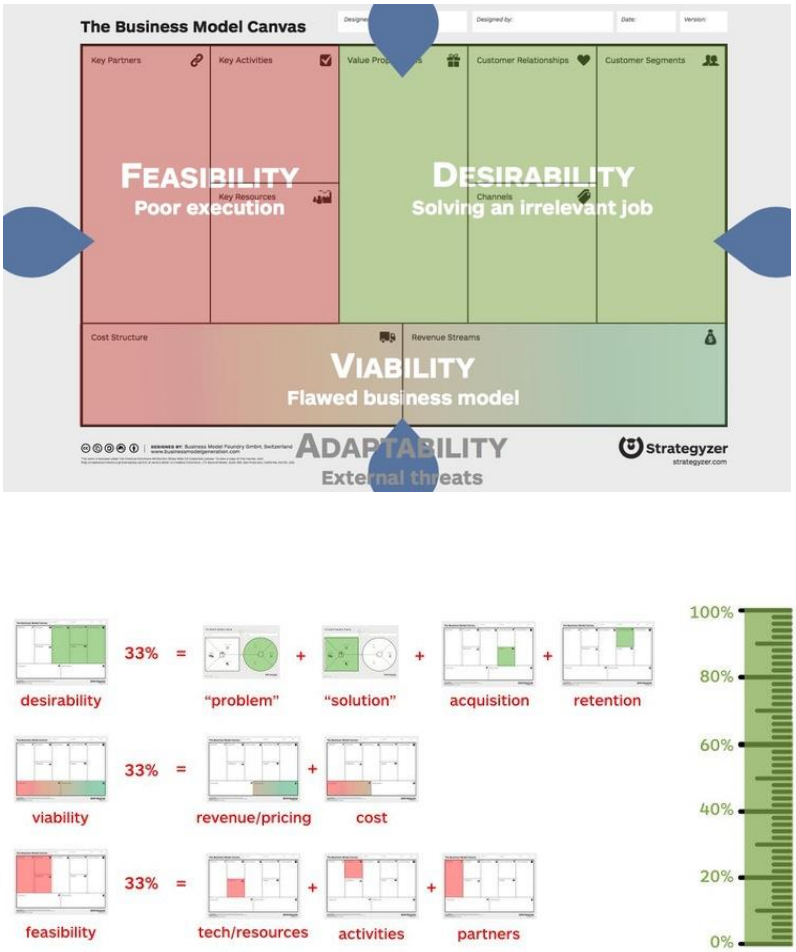


Figure 19. IDEO indicators and the BMC

In Figure 19, *Desirability* is about solving a customer job. *Feasibility* is related to the execution of the BMC. *Viability* reflects the financial viability of the business model, and *Adaptability* deal with the context of external factors, such as competition, technology change or regulation.

Even though the set of Desirability, Feasibility, Viability, and Adaptability criteria approach are helpful to improve the use of the BMC, they are limited in the following ways:

- The priority of considering these criteria in the BMC is not defined.
- It is not clear how they are measured and whether they are relevant to measure and monitor business model assumptions and ideas.
- Regarding the Desirability, it is not a satisfactory criterion and it is not by being merely *desirable* for customers that a value proposition can solve their jobs or alleviate their pains. The condition of designing *something desirable* is to, first, make sure that it is truly *useful* and thus enables creating a sustainable business.
- The above-mentioned set of criteria do not support the *newness* of an innovation, i.e., it must prove that there is a sufficient degree of novelty. For instance, the innovation can be patented or it is perceived as new by customers.

3.5.1. Proposition of a set of indicators

Within the RID methodology, (Yannou, Farel, et al., 2016) have already proposed, experimented, and validated a set of quantitative *innovativeness* indicators, UNPC (standing for *Usefulness*, *Newness*, *Profitability* and *Concept*) in (Yannou, Farel, et al., 2016) which, comparatively to the Desirability, Feasibility, and Viability of Design Thinking:

- prefers Usefulness to Desirability, which reflects a different view of consumerism and of the role of design in society (see also (Papanek and Fuller, 1972)). In addition, it is possible to quantify the Usefulness indicator in the RID methodology by the evaluation of value buckets.
- gives importance to Newness, which is determining in the context of entrepreneurship where the intellectual property is a precious asset.

This set of indicators (or proofs) has been proved relevant to monitor innovative projects in the context of the Europe's biggest innovation cluster specialized in the *Silver Economy* (i.e., the branch of economy dedicated to improving the well-being of the elderly).

These proofs are adapted by (Bekhradi et al., 2015; Bekhradi et al., 2018a) to the context of innovative startups. In this adaptation, a fifth proof is added to cover the multi-stakeholder environment surrounding startup companies. This proof is called *Stakeholder network (S)*, and covers the Adaptability criterion of IDEO, but it extends

the latter to the broader concept of value network. The UNPC together with the S proof form a comprehensive set of indicators (see Table 6 for a brief definition of each proof). Each proof is detailed through several pieces of evidence (presented in 3.9). Moreover, the UNPCS proofs can be quantitatively estimated[5].

Table 6. UNPC proofs of the RID methodology

Proof type	Definition
Proof of **Usefulness (U)**	Proofs of *Usefulness* exist when important needs in frequent usage situations may be satisfied or covered, people's suffering or pains alleviated or malfunctions of existing systems improved. In case of high usefulness, the market size is likely to be large and, consequently, market esteem for the product high.
Proof of **Newness (N)**	Proofs of *Newness* are composed of three aspects: • Perceived newness by clients or end-users, appreciated and valued by them. • Real technical newness, possibly patentable. • Usage newness. Note that real usage newness may be poorly perceived as the market may be not educated or sensitive.
Proof of **Profitability (P)**	It concerns expected *Profitability* for the company as well as for customers. Profitability is related to costs: • From the viewpoint of producers, this is the elementary margin on a product unit. • From the viewpoint of users, this is the total cost of ownership. Proofs of *Profitability* may also characterize the ability to improve brand image, to increase the average revenue per user, to conquer new markets or to make clients more loyal (higher re-purchasing rate).
Proof of **Concept (C)**	Proofs of *Concept* are twofold: • On the side of users, these are proofs that the conceptual solution or prototype functions effectively and efficiently in expected situations. • On the side of the manufacturer, these are proofs of technological and industrial feasibility.
Proof of **Stakeholder network (S)**	Proofs of Stakeholder network measures the degree to which: • the whole value network is relevant; • partnership decisions are coherent with the global strategy of the company, and • clear networking actions, such as lobbying and building partnerships, are considered or has been initiated.

[5] In general, each proof of the UNPCS set is assessed as the sum of its *impact* (between -3 to +3) and *certainty* (between 0 and 100% with increments of 25%). The value of *impact* depends on the degree of pros (+) and cons (-) of a project or idea. The *certainty* shows the probability that a given proof exists (see (Yannou, Farel, et al., 2016; Bekhradi et al., 2018b) for more details on the evaluation mechanism).

The business model of an innovation is sustainable only if it offers real value to people (or it solves problems and jobs of people) who are willing to pay and cover the costs, provided that the infrastructure and relationships with stakeholders are managed efficiently. Therefore, the UNPCS indicators are relevant to the BMC and can help measure and monitor the relevance of business model assumptions and ideas.

3.5.2. Proposition of a measuring and monitoring mechanism

To combine the UNPCS indicators with the BMC in an effective manner, a dynamic measuring and monitoring mechanism is proposed. This mechanism allows using the BMC in a secure way and through five levels that aim at progressively improving the maturity of the U, N, P, C, and S proofs with regards to the nine building blocks of the BMC.

The first four levels of the mechanism consist in identifying the *high priority proofs* in the relevant blocks of the BMC. At each level, a set of questions must be systematically responded by the company. These questions are based on the 30 pieces of evidence of the UNPCS proofs detailed in 3.9.

At the first level, the company makes sure that value buckets are identified and they have been embedded into the Customer Segments (CS) and Value Proposition (VP) blocks. The underlying question at this level is: "*to what extent the VP offers real value to CS by absorbing the identified value buckets with a bundle of products and services that are perceived as new and original*?". Therefore, the first level involves the verification of the proofs of Usefulness (U) and Newness (N) that are very relevant to the CS and VP blocks. In Figure 20, the U and N proofs are indicated by "+++" in the matrix. A traffic light with five lenses, each reflecting a proof, is proposed as a visual support into the BMC template. The first two lenses (for U and N) are green at this level.

(1)

BMC block/RID innovativeness proof Proof not existing 0 proof very little present + Relevant proof ++ Very relevant proof +++	Usefulness (U)	Newness (N)	Profitability (P)	Concept (C)	Stakeholder network (S)
Customer Segment (CS)	+++	+++			
Value Proposition (VP)	+++	+++			
Channels (C)					
Customer Relationship (CR)					
Revenue Streams (RS)					
Key Activities (KA)					
Key Resources (KR)					
Key Partnerships (KP)					
Cost Structure (CT)					

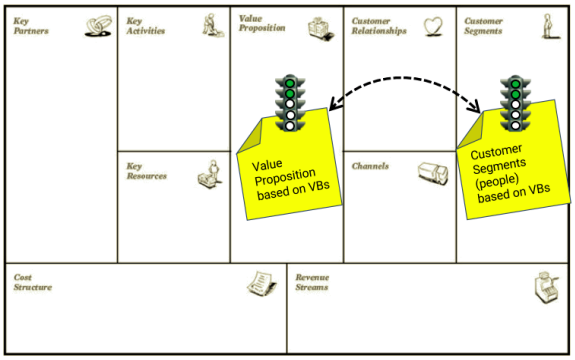


Figure 20. Level 1 of the mechanism (BMC and UNPCS)

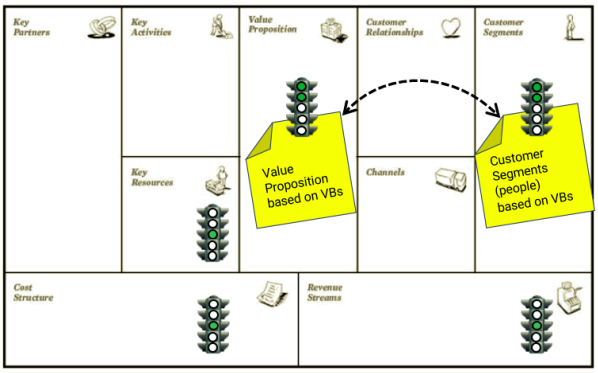
The second level verifies whether the proof of Profitability is mature enough in the three related blocks of the BMC (i.e., Revenue Streams (RS), Key Resources (KR), and Cost Structure (CT)). At the second level, the underlying question is: "*what is the degree of relevance of the identified costs and the willingness to pay of customers in the CS, RS, and KR blocks?*". As the KR affect the CT, the proof of Profitability is considered as very relevant in this block too (see Figure 21).

At the third level, Customer Segments (CS) and Value Proposition (VP) as well as the Key Activities (KA) are concerned by the proof of Concept. The KA are relevant regarding the proof of Concept, as they are responsible of making the production of the VP more effective (see Figure 21).

The fourth level questions the proofs of Stakeholder network in the blocks of the BMC where this proof must be verified in priority. These blocks are: Customer Segments (CS), Channels (C), Customer Relationships (CR), and Key Partnerships (KP).

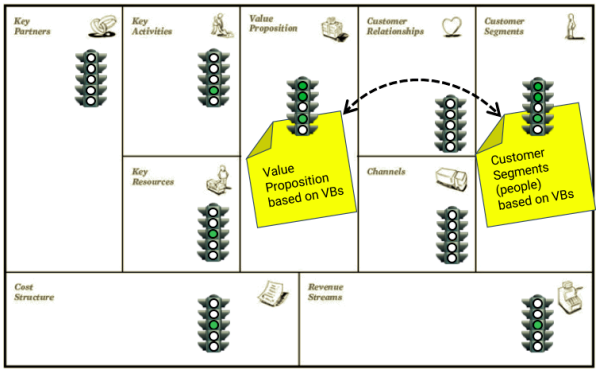
(2)

BMC block/RID innovativeness proof Proof not existing 0 proof very little present + Relevant proof ++ Very relevant proof +++	Usefulness (U)	Newness (N)	Profitability (P)	Concept (C)	Stakeholder network (S)
Customer Segment (CS)	+++	+++			
Value Proposition (VP)	+++	+++			
Channels (C)					
Customer Relationship (CR)					
Revenue Streams (RS)			+++		
Key Activities (KA)					
Key Resources (KR)			+++		
Key Partnerships (KP)					
Cost Structure (CT)			+++		



(3)

BMC block/RID innovativeness proof Proof not existing 0 proof very little present + Relevant proof ++ Very relevant proof +++	Usefulness (U)	Newness (N)	Profitability (P)	Concept (C)	Stakeholder network (S)
Customer Segment (CS)	+++	+++		+++	
Value Proposition (VP)	+++	+++		+++	
Channels (C)					
Customer Relationship (CR)					
Revenue Streams (RS)			+++		
Key Activities (KA)				+++	
Key Resources (KR)			+++		
Key Partnerships (KP)					
Cost Structure (CT)			+++		



(4)

BMC block/RID innovativeness proof Proof not existing: 0 proof very little present: + Relevant proof: ++ Very relevant proof: +++	Usefulness (U)	Newness (N)	Profitability (P)	Concept (C)	Stakeholder network (S)
Customer Segment (CS)	+++	+++		+++	+++
Value Proposition (VP)	+++	+++		+++	
Channels (C)					+++
Customer Relationship (CR)					+++
Revenue Streams (RS)			+++		
Key Activities (KA)				+++	
Key Resources (KR)			+++		
Key Partnerships (KP)					+++
Cost Structure (CT)			+++		

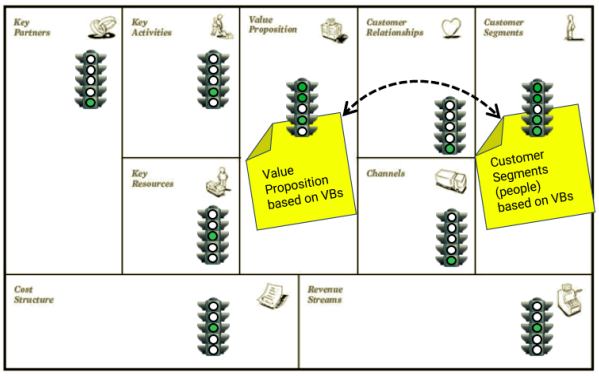


Figure 21. Level 2, 3, and 4 of the BMC-RID mechanism (BMC and UNPCS)

Finally, the fifth level of the mechanism proposes a new BMC to be reached according to the maturity of the UNPCS proofs in the related blocks of the BMC that we consider as relevant (see Figure 22). The maturity degrees shown in the matrix of Figure 22 refer to a required degree of the UNPCS proofs in appropriate blocks of the BMC. Once these maturity degrees are reached, the experiments can be launched in secure way. Indeed, business model assumptions are now justified and uncertainties are reduced. To increase these maturity degrees and to refine the business model, agile experiments must be then conducted by the company. The use of sticky notes can be abundant at to design relevant experiments.

(5)

BMC block/RID innovativeness proof Proof not existing: 0 proof very little present: + Relevant proof: ++ Very relevant proof: +++	Usefulness (U)	Newness (N)	Profitability (P)	Concept (C)	Stakeholder network (S)
Customer Segment (CS)	+++	+++	++	+++	+++
Value Proposition (VP)	+++	+++	++	+++	++
Channels (C)	++	++	++	+	+++
Customer Relationship (CR)	++	++	++	0	+++
Revenue Streams (RS)	+	+	+++	++	+
Key Activities (KA)	0	0	+	+++	++
Key Resources (KR)	0	0	+++	++	++
Key Partnerships (KP)	0	0	++	+	+++
Cost Structure (CT)	+	+	+++	+	+

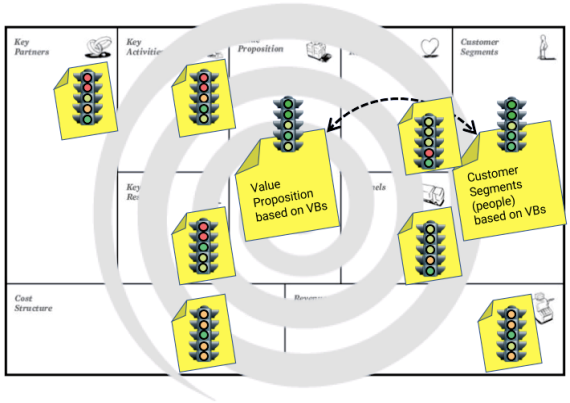


Figure 22. Level 5 of the mechanism (BMC and UNPCS)

The proposed mechanism has been tested through workshops with a technology-oriented innovative startup, and with the students enrolled in an innovation course of the second year of a French engineering school[6]. The details of these experiences exceed the scope of this paper. But, we would only highlight that the participants to these workshops, who had already some preliminary background and experience in using the BMC, had found this mechanism structuring and rational. They have also

[6] This course is called Radical Innovation, see the course website: http://rid.centralesupelec.fr/

mentioned that this way of using the BMC provides proofs and general metrics that are missing in the Canvas. It should be noted that the group of students who was closely coached with the proposed mechanism won the prize of business and innovation offered at the end of this course by a jury of experts in innovation (CentraleSupélec, 2016).

3.6. Summary: three guidelines for a wiser use of the BMC

In summary, the process of problem exploration prior to the BMC (see Section 3.4) as well as the five-level mechanism, explained in previous section, form together the BMC-Radical Innovation Design® (RID) technique (called the "BMC-RID method"). To implement the BMC-RID in a more practical way, three guidelines are proposed in the following.

First: carefully identify the overlooked yet important problems of customers/end-users and compute the value buckets before developing the BMC

A systematic problem exploration must be conducted to identify and quantify value buckets. The latter is indeed a more structured approach that merely empathizing with user as advocated by the Design Thinking (Brown, 2009) or running trial-and-error loops.

This exploration is distilled into a set of quantified value buckets (i.e., useful problems occurring in frequent usage situations for which the existing solutions are not efficient). This set is then prioritized and is shrunk into an ambition perimeter according to the startup strategy and product development priorities. Subsequently, this ambition perimeter feeds the Customer Segment and Value Proposition blocks of the BMC.

Second: start to develop a BMC based on the identified value buckets and increase the maturity of the UNPCS proofs in the appropriate blocks

First, make sure that value buckets in an ambition perimeter are addressed in the Value Proposition and Customer Segments blocks. This will improve the process of filling up the BMC and help save time and effort. Here, the originality of our BMC-RID proposition is that we start feeding the BMC with the description of relevant problem seeds (or value buckets) instead of directly developing the business model based on an unjustified value offer.

Second, transform these problem seeds into relevant solutions and increase the maturity of the UNPCS proofs in appropriate blocks of the BMC following the five-level

mechanism explained previously (see from Figure 20 to Figure 22). Once the minimum maturity of the UNPCS proofs is reached in all BMC blocks, assumptions and ideas are formulated before conducting experiments.

Finally: launch experiments in a secure way and advance progressively in the BMC to increase the maturity of the UNPCS proofs

Since the UNPCS proofs have already reached a satisfactory level of their maturity in the BMC, the uncertainties are reduced and the launch of experiments is now more secured. Relevant business model assumptions can be formulated based on the pieces of evidence of the UNPCS proofs. These assumptions are then verified through experimentation.

The Testing Process of the Value Proposition Design (VPD) can be implemented at this stage. Test actions must be linked to business model assumptions. To do so, the Test Card of the VPD approach seems to be a practical tool.

As such, the BMC-RID provides a more structuring process for using the BMC and allows obtaining sound results and not naïve ones.

3.7. Discussions and Conclusion

The Business Model Canvas (BMC) is a qualitative and informal tool which is very popular among innovative startups. Even though this canvas is not a problem exploration approach, most startups apply it from early development stages. Besides, they launch experiments based on the assumptions, expressed in the blocks of the BMC, without necessarily verifying their relevance.

To make the use of the BMC more rational, this paper has proposed a hybridization of the BMC with the usage-driven methodology called Radical Innovation Design® (RID). This hybridization, called BMC-RID method, helps initiate the BMC with a solid definition of Value Proposition and Customer Segments based on prioritized value buckets resulting from the RID Problem Setting sub-process. Furthermore, the continuous assessment of the BMC based on the UNPCS proofs reduces uncertainties and allows to converge, in a secure manner, towards a business solution of a high value.

Compared to the Lean Canvas approach (Maurya, 2012), the BMC-RID method provides a more formal way to explore, elicit, and prioritize problem seeds (called value buckets). Moreover, compared to the BMC and its variants, BMC-RID provides quantitative indicators to evaluate and monitor the relevance of assumptions and

ideas in a business model. Therefore, we may reasonably consider the BMC-RID as a new variant of the BMC.

Finally, the combination of the UNPCS proofs with the BMC can be used to diagnose an existing business. This will allow detecting the weaknesses in terms of the UNPCS proofs to be tackled. In our future work, we will implement the BMC-RID as a diagnostic tool in the context of startups. The latter will allow identifying the deficiencies of an innovation to formulate further improvement recommendations and to express relevant experiments.

3.8. References

Aulet, B. (2013). *Disciplined entrepreneurship: 24 steps to a successful startup*: John Wiley & Sons. 1118720814.

Aungst, S., Barton, R., and Wilson, D. (2003). The virtual integrated design method. *Quality Engineering, 15*(4), 565-579.

Bekhradi, A., Yannou, B., and Cluzel, F. (2018a). Do innovative startups rigorously design and test a product or service? *Submitted to Journal of Small Business Management*.

Bekhradi, A., Yannou, B., and Cluzel, F. (2018b). *Evaluating and selecting promising innovative projects: the UNPC model for innovativeness*. Retrieved from CentraleSupélec.CentraleSupélec:

Bekhradi, A., Yannou, B., Cluzel, F., Chabbert, F., and Farel, R. (2015). *In Vivo In Situ Experimentation Projects by Innovative Cleantech Start-Ups in Paris*. Paper presented at the ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. http://dx.doi.org/10.1115/DETC2015-47631

Blank, S. (2013). Why the Lean Start-Up Changes Everything. *Harward Business Review*.

Blank, S. (2014). Watching My Students Grow. Retrieved from: https://steveblank.com/2014/10/03/my-students-grow-into-a-company/. Access date: August 2018.

Blank, S. (2018). Blue River Technology Founders Story. 2 Minutes to See Why. Retrieved from: https://www.youtube.com/watch?v=Tniuzj2AjHQ. Access date: July 2018.

Brown, T. (2009). *Change by design: How Design Thinking Transforms Organizations and Inspires Innovation*. New York, United States: HarperBusiness.

CentraleSupélec. (2016). Prix d'innovation CIPS 2015. Retrieved from: http://rid.centralesupelec.fr/en/node/214. Access date: July 2018.

Christensen, C. (2013). *The innovator's dilemma: when new technologies cause great firms to fail*. Massachusetts, United States: Harvard Business Review Press. 9781633691780.

Hanshaw, N., and Osterwalder, A. (2015). The business model canvas: Why and how organizations around the world adopt it (A field report from Strategyzer). Retrieved from: https://blog.strategyzer.com/posts/2015/2/9/why-and-how-organizations-around-the-world-apply-the-business-model-canvas. Access date: July 2018.

IDEO, D. K. (2015). The field guide to human-centered design: IDEO Canada.

Ishikawa, K. (1976). *Guide to quality control: industrial engineering and technology*: Asian Productivity Organization Tokyo, Japan. 9283310365.

Jaruzelski, B., Staak, V., and Shinozak, A. (2016, Winter 2016). Global Innovation 1000 : Software-as-a-Catalyst, The world's largest innovators are shifting the focus of their R&D investments from products to programming. *strategy+business*.

Joyce, A., and Paquin, R. L. (2016). The triple layered business model canvas: A tool to design more sustainable business models. *Journal of cleaner production, 135*, 1474-1486.

Kim W.C., and Mauborgne, R. (2005). *Blue Ocean Strategy: How to Create Uncontested Market Space and Make Competition Irrelevant*: Harvard Business Press.

Lamé, G., Leroy, Y., and Yannou, B. (2017). Ecodesign tools in the construction sector: Analyzing usage inadequacies with designers' needs. *Journal of cleaner production, 148*, 60-72.

Massa, L., and Tucci, C. L. (2013). Business model innovation. *The Oxford handbook of innovation management, 20*(18), 420-441.

Maurya, A. (2012). *Running lean: iterate from plan A to a plan that works*: " O'Reilly Media, Inc.". 1449331912.

Osterwalder, A. (2014). Why We Created Value Proposition Design. Retrieved from: https://blog.strategyzer.com/posts/2014/9/29/value-proposition-design. Access date: July 2018.

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey, United States: Wiley. 9780470901038.

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., and Papadakos, T. (2015). *Value Proposition Design: How to Create Products and Services Customers Want*. New Jersey, United States: Wiley. 9781118968055.

Papanek, V., and Fuller, R. B. (1972). *Design for the real world*: Thames and Hudson London. 0500231656.

Porter, M. E. (1985). How information gives you competitive advantage. *Harvard Business Review, 63*(4), 149-160.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

Riley, K. (2014). modelH Business Model Canvas for Healthcare. Retrieved from: https://www.behance.net/gallery/13500371/modelH-Business-Model-Canvas-for-Healthcare. Access date: August 2018.

Savransky, S. D. (2000). *Engineering of creativity - Introduction to TRIZ Methodology of Inventive Problem Solving*: Boca Raton.

Schwenk, C., and Thomas, H. (1983). Formulating the mess: The role of decision aids in problem formulation. *Omega, 11*(3), 239-252.

Shafer, S. M., Smith, H. J., and Linder, J. C. (2005). The power of business models. *Business horizons, 48*(3), 199-207.

Souchkov, V. (2010). *TRIZ and systematic business model innovation.* Paper presented at the 10 th ETRIA world TRIZ future conference. bergamo university press. Italy.

Spradlin, D. (2016). Are you solving the right problem? *IEEE Engineering Management Review, 44*(4), 47-54.

Teece, D. J. (2010). Business models, business strategy and innovation. *Long range planning, 43*(2-3), 172-194.

Trimi, S., and Berbegal-Mirabent, J. (2012). Business model innovation in entrepreneurship. *International Entrepreneurship and Management Journal, 8*(4), 449-465.

Wedell-Wedellsborg, T. (2017). Are you solving the right problems? *Harvard business review, 95*(1), 76-83.

Yannou, B. (2015). *Supporting need seeker innovation: the Radical Innovation Design methodology.* Paper presented at the International Conference on Engineering Design (ICED).

Yannou, B., Cluzel, F., and Farel, R. (2016). Capturing the relevant problems leading to pain and usage driven innovations: the DSM Value Bucket algorithm. *Concurrent Engineering: Research and Applications*, 1 - 16. doi:10.1177/1063293x16666311

Yannou, B., Farel, R., Cluzel, F., Bekhradi, A., and Zimmer, B. (2016). The UNPC innovativeness set of indicators for idea or project selection and maturation in healthcare. *International Journal of Design Creativity and Innovation, 5*(3-4), 205-221. doi:10.1080/21650349.2016.1161562

Yannou, B., Jankovic, M., Leroy, Y., and Okudan Kremer, G. E. (2013). Observations from radical innovation projects considering the company context. *Journal of Mechanical Design*. doi:10.1115/1111.4023150

Zott, C., Amit, R., and Massa, L. (2011). The business model: recent developments and future research. *Journal of management, 37*(4), 1019-1042.

3.9. Appendix: UNPCS proofs and their pieces of evidence

Proof Type	Evidence
Proof of Usefulness (U)	Definition of the problem to be solved Relevance of the identified usage situations Definition of the value buckets and the ambition perimeter (a selection of value buckets) Covering the identified value buckets Systematic exploration of the existing solutions Appropriateness of the project for other stakeholders
Proof of Newness (N)	Knowledge of the value chain Legal and patent watch Technical and economic scouting Degree of usage newness
Proof of Profitability (P)	Financial management of the project development and experimentation Cost breakdown structures Sources of revenues Identified sale channels Willingness to pay of customers/end-users Marginal cost of production Relevance of the identified key resources to the project
Proof of Concept (C)	Relevance of the identified key activities to the project Description of the concept Planning of the project's design activities Degrees of skill and knowledge of the project provider or entrepreneur Prototype development strategy Project risk analysis Project development milestones validation process Products robustness and reliability of materials in extreme usage conditions
Proof of Stakeholder network (S)	Relevance of project partners Ability to introduce the project and communicate (skills in *pitch*) Strategy for obtaining current or desired support for the project Ability to fund the project development or experimentation via adapted fundraisings Ability of lobbying or persuasion

Chapter 4. Paper #4: Identifying relevant market gaps through experimentation: proposition of the Design by Usage-based Experimentation (DUE) methodology

This paper is submitted to Research in Engineering Design in November 2018, under the following reference:

- Bekhradi, A, Yannou, B., and Cluzel, F. (2018). Identifying relevant market gaps through experimentation: proposition of the Design by Usage-based Experimentation (DUE) methodology, *Submitted to Research in Engineering Design*.

Foreword

The intermediary conclusions of this thesis showed that experimentation approaches for innovative entrepreneurship advocate merely loop-based tests without indicating which markets and technology aspects the startup must focus on. Therefore, such loop-based tests remain uncertain and rather unstructured.

This chapter aims at providing a methodology called Design by Usage-based Experimentation (DUE) to better organize experiments in the context of a technology-oriented innovative startup. A rigorous process as well as several tools and deliverables are proposed by the DUE to deal with the issue of chaotic, random and merely loop-based tests.

Abstract: R&D investment in technology-oriented innovative startups is extensively focused on prototyping and testing activities. Due to important uncertainties in early innovation phases, startup investments are motivated by the pressing need of building and repeatedly testing a Proof of Concept (PoC) without necessarily delineating the innovation problem to be addressed. Following this mindset, the startup ends up running loop-based experiments that can lead to costly pivots and even to failure.

Thus, the relevance of such experiments becomes questionable in the context of limited time and resources of startups. Looking at the interdisciplinary literature, it appears that the existing methods and tools fail at providing startups with practical tools allowing them to specify experiments which address relevant gaps in the market. To address this issue, this paper proposes a new usage-driven methodology called Design by Usage-based Experimentation (DUE). This methodology provides a structured process along with a set of tools to identify experiments that are worthy to be conducted, insofar as they focus on gaps in the market characterized by value buckets (i.e., important problems occurring in frequent usage scenarios for which the existing solutions are not efficient). The main output of the DUE process is a set of experimentation opportunities to make mature the core technology of a startup, that are computed by matrices linking the promising markets to the main properties of the technology. The identified opportunities (or meta value buckets) then serve as a target to define relevant hypotheses and actions in terms of experimentation. This paper also presents the results of the application of the DUE methodology to the case of a technology startup with a multi-market core technology. We conclude that this methodology generates useful insights and may help startup with structuring and organizing their experiments.

Keywords: R&D activity, experimentation, usage, market, property of the technology, value bucket.

4.1. Introduction

"*Most startups fail because they waste too much time and money building the wrong product before realizing too late* [and after trials and errors] *what the right product should have been*" emphasizes Professor Thomas R. Eisenmann (Nobel, 2011). Although there is no clear definition of a startup, many researchers and practitioners consider it as equivalent of continual experimentation (Ries, 2011; Blank, 2013b). The aim of any innovative startup is to transform the initial idea to a successful product. To do so, startup companies build several Proofs of Concept (PoC) and then test (or experiments)[7] them repeatedly to verify whether this is the right product or not. These experiments are costly and time-consuming and can lead to several pivots and even to failure.

This situation is even more observable in the context of technology startups, that develop a core technology and adopt testing and business strategies to launch a new

7 "Test" and "experiment" are used interchangeably in this paper. Even though they may have some differences, in general they have more similarities than differences. As indicated by (Kass, 2008), terminology confusion suggests a close connection between test and experiment. A test is to assess the presence, quality, or genuineness or anything. An experiment is about exploring the effects of manipulating a variable.

product on the market. Indeed, these startups require an important number of resource-intensive experiments to make their technology mature. They also need to effectively align both technology development and market penetration strategies to reduce the number of pivots and the use of resources. However, in the situation where the technology is not a good fit to a given unsolved or poorly-solved problem on the market, the number of pivots and thus waste in resources might be very important. Therefore, the effectiveness of experiments becomes a crucial challenge in the context of limited time and resources of startups.

Considering that 73% of startups are technology-driven, and that this number has been increased by more than 47% during the last decade (Wu and Atkinson, 2017), one may consider that challenges related to wisely investing in experimentation affect a large portion of the entrepreneurial ecosystem including not only entrepreneurs, but also other players such as investors as well as public and private organizations supporting innovative startups.

A large body of literature in the innovation management, technology management and engineering design already deals with the question testing and prototyping an innovation. In an entrepreneurial context, several methods and tools, such as the Lean Startup (Ries, 2011), provide experimentation guidelines to startups. The common point of these methods and tools is that they put a strong emphasis on loop-based testing an innovative product or service to improve its technical and business performances.

Nevertheless, the review of the interdisciplinary literature shows that the existing methods and tools provide no satisfactory guidelines to identify which market and property of the technology are relevant to be targeted through experiments. Besides, the existing approaches concentrate on the test of a solution without necessarily backtracking on end-users' problem to be solved.

Therefore, the question addressed in this paper is: **how to identify the most promising markets and the properties of the technology that a technology-oriented innovative startup should target through experimentation, with limited resources and time?**

To address this question, this paper puts forward a methodology which aims at thoroughly specifying the experiments through the exploration of relevant usages and promising markets. This methodology is called DUE standing for *Design by Usage-based Experimentation* which follows a set-based thinking approach (see for instance (Yannou, Yvars, et al., 2013; Sobek et al., 1999; Kennedy, 2008)). Indeed, the set-based design, unlike the trial-and-error approach, consists in reducing uncertainties to progressively converge to a satisfactory solution.

DUE is a systematic diagnostic approach that starts with evaluating the potential of an existing technology in different markets and identifying the areas where it is worth conducting experiments. These areas represent a gap between the current maturity of the technology and its expected maturity in the most promising markets. In DUE, the promising markets are characterized by value buckets (i.e., important problems occurring in frequent usage scenarios for which the existing solutions are not efficient). The concept of value bucket is borrowed from the Radical Innovation Design® (RID) methodology (Yannou, Jankovic, et al., 2013; Lamé et al., 2018; Yannou et al., 2018) which follows set-based thinking. Moreover, RID is compliant with the *need seeker* innovation strategy (Jaruzelski et al., 2016) that encourages the development of new products and services based on superior end-user understanding.

The main contribution of this article, is to provide a set of practical tools to practitioners to help them identify a set of promising markets as well as the key properties of the technology that must be matured through experiments. This is a new result insofar as a structuring process along with some quantitative evidences are provided to specify and prioritize experiments. Besides, academics can find these findings useful because of the structured process for experimentation proposed by the DUE methodology.

The organization of this paper is the following: in section 4.2, the background of DUE in the literature of engineering design, technology and innovation management fields are presented. In Section 4.3, the DUE methodology and its components are outlined. We then focus in Section 4.4 on the application of DUE to the case of startup that have patented a shape-changing technology. Finally, Sections 4.5 and 4.6 summarize and discuss the results in light of the reviewed literature, and interpret the significance of the DUE methodology comparing to the existing methods and tools.

4.2. Background literature on design and experimentation approaches

In this section, we are seeking to understand what are the design and experimentation approaches to new product development. To do so, the subsection 4.2.1 reviews design and creativity approaches and the subsection 4.2.2 focuses more specifically on experimentation processes and their components.

4.2.1. Design and creativity approaches

There is a plethora of design and creativity methods and tools. In the following, we will detail some of them relevant to the context of this research. They are mainly derived from the fields of engineering design and technology management.

The **C-K theory** (Hatchuel and Weil, 2009) builds on conventional creativity and design theories and its design process is considered as a series of back and forth between knowledge (K) and concept (C) spaces. In practice, C-K theory is a qualitative innovative problem-solving mechanics that helps designers understand problems and find creative solutions. However, there is no differentiation between concepts or knowledge regarding a design problem or a solution. In addition, C-K theory does not specify the notions of usage, innovativeness or value indicators, market, and existing technologies, as well as the cost and time of development.

Another qualitative design approach is the **Double Diamond model** for product design that has been created by the UK Design Council in 2005 (DesignCouncil, 2005). This model contains two macro-stages and four steps: Discover, Define, Develop and Deliver. Although this approach is a very useful and structured, it does not necessarily focus on the design and test of a technology and does not provide practical tools.

Consistent with the divergent macro-stages of Double Diamond model, the first step of **Product Design and Development model of Ulrich and Eppinger** (Eppinger and Ulrich, 1995) begins with discovering customer needs and screening opportunities on the market. However, the identification of customer needs is performed through market studies rather than systematically exploring usage situations and the users' problems occurring in these situations.

TRIZ is another approach to inventive problem solving. It is a useful and widely-used theory in the context of technology companies. However, it does not claim to be a holistic design and testing approach insofar as the notions of usage, quantitative indicators related to the market and cost evaluation are missing. Unlike the previous analyzed approaches, the power of TRIZ lies in an algorithm called ARIZ to isolate the problem to be solved, the Contradiction Matrix, Laws of Technical System Evolution, substance-field analysis as well as the concept of ideality of a system. Scientific publications on TRIZ and its extensions on technology development are abundant (see for instance (Cascini et al., 2011; Cascini et al., 2009).

Other popular approaches widely used in organizations are the **Quality Function Deployment (QFD)** (Akao et al., 1990) and the matrix flow approach of Nam Suh's **axiomatic design model** (Suh, 2001). They serve as a decision making tool that transforms the Voice Of the Customer (VOC) into engineering characteristics for a product. Even though a large amount of data on customer needs are stored and used in QFD matrices, the collected data does not systematically allow to explore users' pains and usage situations.

The process of transforming VOC data to design requirements in QFD calls for other approaches such as the Six Sigma methodology. Six Sigma is combined with the lean process to become **Lean Six Sigma (LSS)** (George, 2002), and to reduce wastes while improving the quality of the product service system. The LSS process starts with *defining* the VOC. The benefits of using LSS in companies are important. Nevertheless, listening and specifying the VOC requires that customers are able to express their problems, needs, and expectations. This is not always true and is not necessarily linked to the efficiency of the existing technologies on the market.

To characterize real problems, and beyond immediate customer expectations, the **Radical Innovation Design® (RID)** methodology is a systematic detection of *value buckets*, i.e., the combinations of important problems occurring in frequent usage scenarios and for which existing solutions are neither useful nor efficient (Yannou et al., 2016). RID is a usage and pain-driven method that enables to design inventories of existing solutions, usage situations (or scenarios) and pain points (or problems) of users. However, the RID methodology is not conceived to screen several usages and exploring a technology base instead of an initial idea. Besides, time and cost of technology experiments are not systematically incorporated to the process and tools of RID.

In summary, the reviewed methods and tools either do not specify usage situations, markets and existing technological solutions, or they fail at specifying and designing relevant experiments.

4.2.2. Methods and tools for experimentation

An experiment is defined as a set of organized measurements carried out under specific and controlled conditions and objects to discover, verify, or to illustrate a theory, hypothesis, or relationship. The experimentation approaches can be analyzed through four main components: *processes*, *decision making tools*, *test objects*, and *hypotheses*.

4.2.2.1. *Experimentation processes*

More often, experimentation processes are iterative or “non-linear” because of the existence of back loops. In **Design Thinking (DT)** the results of prototype testing are re-used as input for the next round of development (Johansson-Sköldberg et al., 2013). (Brown, 2009) emphasizes: it is through the process of repeated creating, testing and learning that entrepreneurs can improve their initial ideas (see Figure 23).

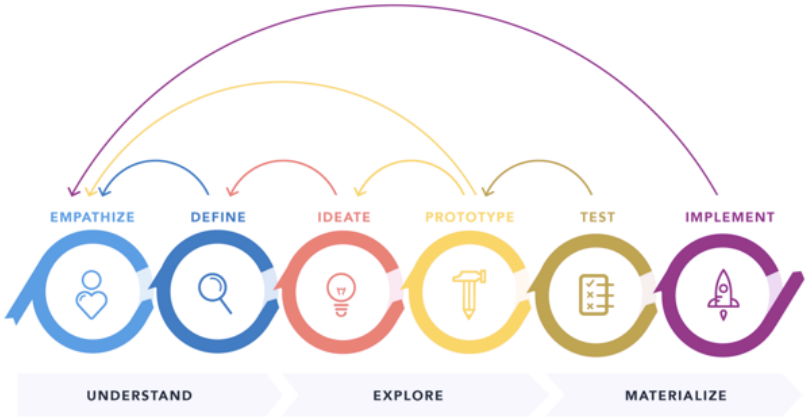


Figure 23. Design Thinking iterative process (Gibbons, 2016)

In DT, the prototyping and testing are combined modes and consists in iteratively developing several solutions (or prototypes) to collect several users' feedbacks.

Comparable to the iterative process of DT, **the Lean Startup (TLS)** process makes a particular focus on experimentation. TLS is based on Steve Blank's **Customer Development process** (Blank, 2013a) and complies with other approaches such as Lean Manufacturing and agile software development. The process of TLS intends to reduce uncertainties by continuously running the *build-measure-learn* loops. The Lean Startup offers an alternative to conventional business planning methods (Ries, 2011).

Inspired by the *build-measure-lean* loops, the **Value Proposition Design (VPD)** (Osterwalder et al., 2015) puts forward a testing process which consists in extracting relevant hypotheses from the Business Model Canvas, Value Map and Customer Segment (see Figure 24).

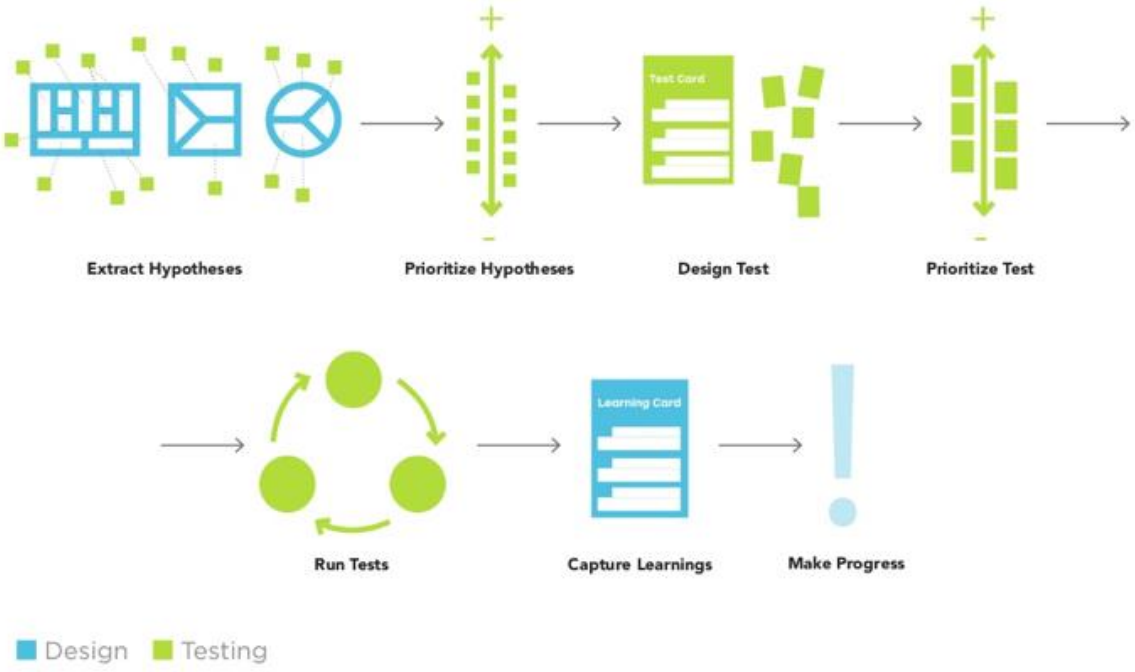


Figure 24. Testing process of the Value proposition Design (Osterwalder et al., 2015)

Very similar to Ries' loop, Thomke proposes a **Learning Cycle process**, that contains four iterative steps beginning with the design requirements in the company. Following several years of empirical research in large companies, Thomke showed that a technology can be developed and commercialized more efficiently when many iterations are run. In his book (Thomke, 2003), he compared the impact of computer simulation and rapid prototyping in terms of efficiency which is defined as the number of eliminated errors divided by the costs.

From the engineering design perspective, several new product development approaches with a specific focus on testing can be mentioned, such as **Stage-Gate® Model** (Cooper, 1990), **Verification and Validation (V&V)** procedures. These approaches ensure that a product-service meets the design requirements and complies with regulation and specifications (Babuska and Oden, 2004). Another rigorous way of experimenting the performances of a technology is the **DOE (Design of Experiments)** or experimental design (Fisher, 1937). DOE is a statistical method that consists in predicting the outcomes of a system following the change of independent variables. However, this method is not yet adapted to the context of entrepreneurship (Frederiksen and Brem, 2017).

In a nutshell, the above-mentioned processes encourage carrying out loop-based tests, most often very late in the design process, and they do not necessarily enable to verify whether the innovation problem is well-expressed or not.

4.2.2.2. *Tools to support decision making in experimentation*

A tool is more often understood as a means to activate and operate a function. To assist the decision making of innovators, there is an important number of visual tools: for instance, graphical canvases and dashboards, test and learning cards (Osterwalder et al., 2015), see Figure 25); indicators such as the TRL (technology readiness level); as well as more conceptual tools such as customer interviews. The Business Model Canvas (BMC), Value Map and Customer Segment are very often used as supports for experimentation in the context of startups.

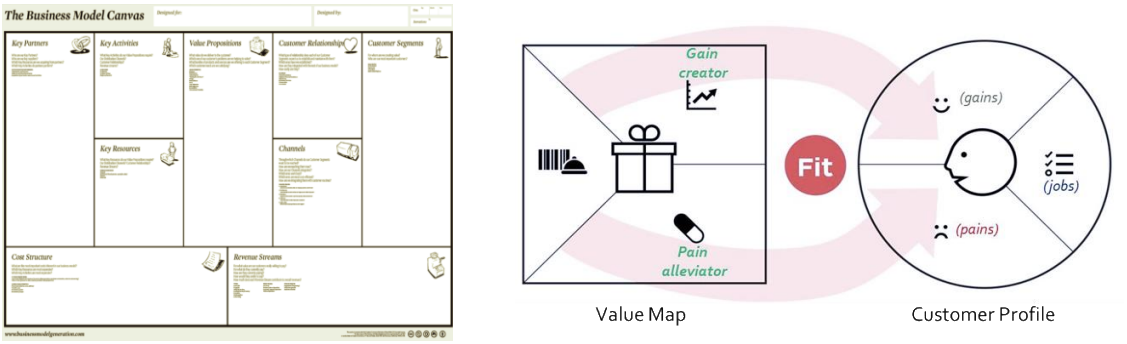


Figure 25. Business Model Canvas (BMC) (right) and Value Map and Customer Profile (right) (Osterwalder and Pigneur, 2010; Osterwalder et al., 2015)

Other tools, such as Test Cards (see Figure 26) and Learning Cards are directly implemented in testing. In addition, TLS or DT propose a set of tools for a given action or step of the innovation process in a more opportunistic way. These tools can be customer interviews, observation techniques, mind mapping, value chain analyses, concierge, A/B tests and fake door tests.

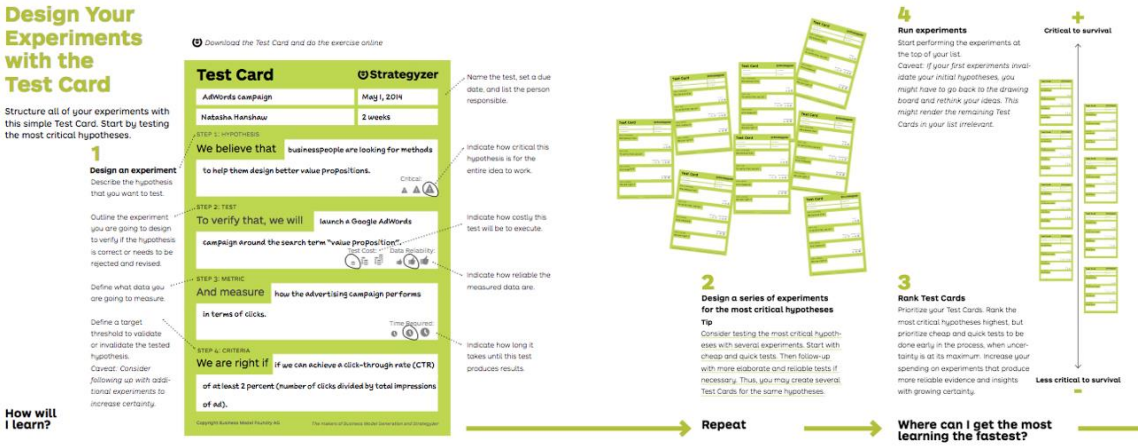


Figure 26. Test Cards of the Value Proposition Design (Osterwalder et al., 2015)

Although these tools are supposed to bring useful insights to entrepreneurs, they fail at providing quantitative evidences to back the investment decisions in experimentation.

4.2.2.3. *Test objects*

A test object is a physical or virtual model built to test something or to act as replicate of something. These objects could encompass simulation models, service prototypes, Minimum Viable Product (MVP)[8], or Intermediary Design Objects (IDO)[9] as introduced by (Vinck and Jeantet, 1995).

Conventionally, an experiment is the test of a prototype (“primitive form” in Greek) or proof of concept (PoC) to demonstrate that the concept is realistic and it creates the expected value. A prototype approximates the final product (Ulrich and Eppinger, 2015), and it serves to elicit feedbacks from users, verify that the concept is feasible, and that its expected qualities are achievable.

Prototypes can be categorized in terms of their nature (for instance: physical, virtual or service), but also according to their high or low fidelity (‘lo-fi’ and ‘hi-fi’), i.e., their way of conveying the features of the final product. Hi-fi prototypes (see for instance (Pahl and Beitz, 2013; Ulrich and Eppinger, 2015)) may contain *alpha* prototypes (that are used internally to assess whether the product works as intended), *beta* prototypes (which are generally tested with users), as well as final pilots (or pre-production prototypes). Building hi-fi prototypes may be a time consuming and costly endeavor. One way to limit the resource usage and investment of time is to build lo-fi prototypes

[8] The MVP concept is coined by the Lean Startup approach and consists in a product with just enough features that customers will pay for.
[9] IDO is designed to enhance the development process with the active participation of users.

that can be, among others, sketches, wireframes (i.e., a refined presentation of the concept), and paper-prototype (Snyder, 2003). The lo-fi prototyping seems convenient in the context of limited time and resources of startups. However, the lo-fi or early stage prototypes are often overlooked by entrepreneurs (Clarysse and Kiefer, 2011).

In summary, there is a vast literature on prototyping categories and techniques. Nevertheless, the existing literature lacks in identifying the markets and the properties that a prototype may contain before its production.

4.2.2.4. *Identification of hypotheses*

A hypothesis is a testable proposition to solve a problem. The definition of hypotheses before launching experiments is crucial in the innovation process as it enables innovators to conduct structured experiments rather than trial-and-error ones.

The hypotheses can be identified through different techniques. In the VPD testing approach (see Figure 26) hypotheses are extracted from different canvases. However, this extraction is not systematic and does not allow to verify whether the extracted hypotheses are well-founded. To state and diversify different hypotheses, Steve Blank puts forward a flow for Customer Discovery (Blank, 2013a), that starts from the initial product hypothesis going through the “Problem” and “Product” hypotheses.

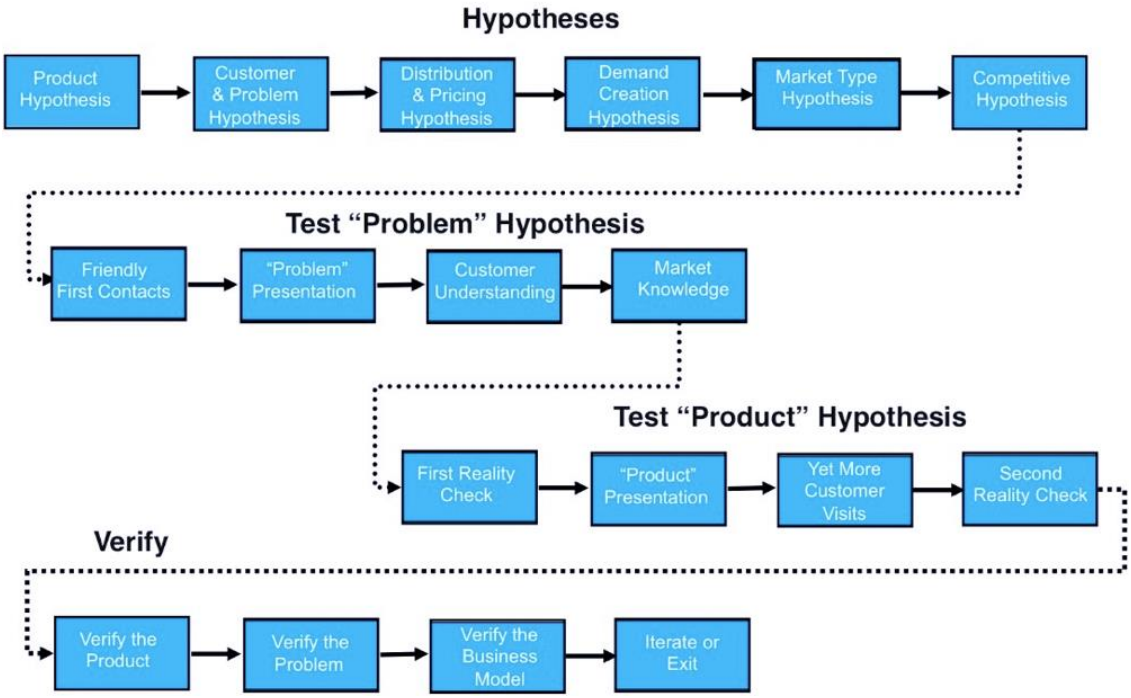


Figure 27. Identification of problem and product hypotheses (Blank, 2013a)

Despite the existence of such techniques to identify hypotheses, it is worth asking whether innovators systematically hone their hypotheses. For Thomke and Manzi, companies lack more often the discipline to identify relevant hypotheses. This might lead to inefficient and costly tests (Thomke and Manzi, 2014). In the context of technology-oriented innovative startups, a useful hypothesis might enable to characterize both market and technology properties from early development stages. Nevertheless, no clear technique exists to back the extraction of relevant hypotheses.

Based on our review of experimentation approaches, we have identified the following lacks: (i) experimentation processes focus on late development stages and do not enable to investigate users' problems and usages, (ii) existing experimentation tools fail at providing quantitative evidences in terms of technology and market priorities, (iii) the existing prototyping techniques do not systematically specify the markets and the properties that a prototype may contain, and (iv) there is no reliable technique to verify whether hypotheses are formulated from a relevant basis.

To fulfill the lacks identified in the literature, this paper aims at presenting a new methodology called Design by Usage-based Experimentation (DUE).

4.3. Introducing the DUE methodology

4.3.1. DUE: fundamental principles

DUE is a new methodology for efficiently testing a technology and specifying the gaps to be addressed through experiments to reach promising markets. DUE and its components are a hybridization of several methods and tools reviewed in the previous chapter. Figure 28 depicts relevant methods and tools to DUE. In this figure, the funnel narrows down towards approaches that have inspired the DUE methodology the most.

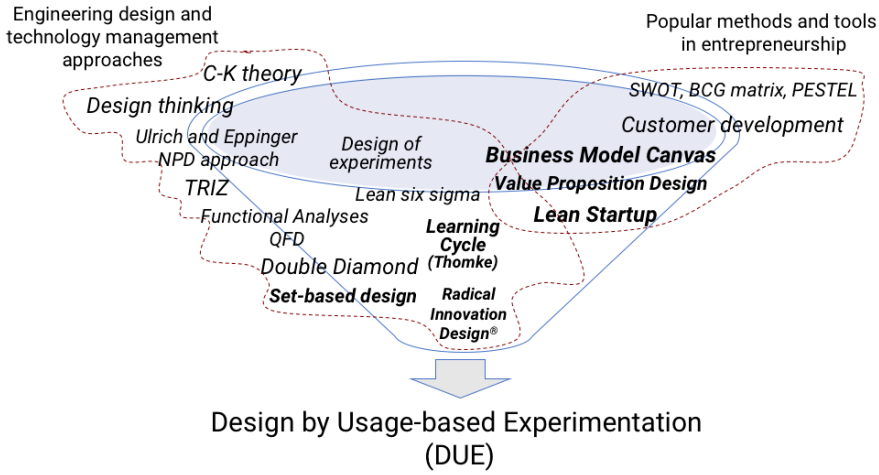


Figure 28. DUE is inspired by the existing methods and tools

DUE is highly inspired by the usage-driven methodology of Radical Innovation Design® (RID) which is founded per se on a set-based thinking approach (Sobek et al., 1999; Kennedy, 2008). The set-based thinking makes a point of reducing uncertainties to progressively converge to a satisfactory solution, in opposition to the point-based design which consists in testing an attractive design and making several design back loops for successively improving the solution. Following a set-based thinking approach, DUE aims at identifying experiments that address markets with high potential of value creation. These markets are identified through a systematic exploration of usage situations and the overlooked problems of users from the front end of innovation. This falls within the *need seeker* innovation strategy (Jaruzelski et al., 2016) which actively and directly engage both current and potential customers to help shape new solutions based on superior end-users understanding.

To gain an in-depth understanding of end-users, it is necessary to focus on the concept of *Usage*, essential to the DUE methodology. Usage is a broad concept and does not have a single definition. It can also be related to other concepts such as: *usage scenario*, *usage context* or *usage situation*. A usage scenario is an archetypal story lived

by a representative group of users, where one may encounter an important problem, whereas a usage context enables to capture personal and environmental factors and lifestyles (He et al., 2012). In DUE, the concept of usage and usage situations not only includes end-user problems, but also enables to quantify the importance of problems and their representativeness. This goes beyond the mere *persona* method[10] with weak understanding of usage situations and their importance.

DUE provides a toolkit to diagnose usage situations in order to identify value creation potentials of a technology in different markets. This diagnostic leads to quantify Value Buckets (VBs) as proposed by the Radical Innovation Design® (RID) methodology (Lamé et al., 2017; Yannou et al., 2016). The systematic identification of VBs in different markets enables to identify promising markets in which the technology has a higher potential of value creation for users.

4.3.2. DUE process

The DUE process (see Figure 29) is structured and is composed of two macro-stages and four steps, each step containing several deliverables as well as tools.

The first macro stage is called “Investigation Stage”. The aim of this stage is to determine: on which markets and technology properties it is worth investing time and effort, since there are overlooked problems of users or important value buckets that could be possibly exploited by the technology. Furthermore, this stage allows to identify technology main properties and to link them to its promising markets in order to quantify the market maturity gap. The intersection between the first and second stages contains thus a justified perimeter of the market maturity gap to be bridged through experiments.

The second stage of the process is called “Planning and Implementation Stage” which aims at specifying and conducting experiments and business strategies. Based on the quantified market maturity gap, experimentation strategies are identified and prioritized in terms of the relative importance of the identified gaps, the cost and time of each experiments.

10 Persona is an imaginary character that embodies the needs and traits of specific target users.

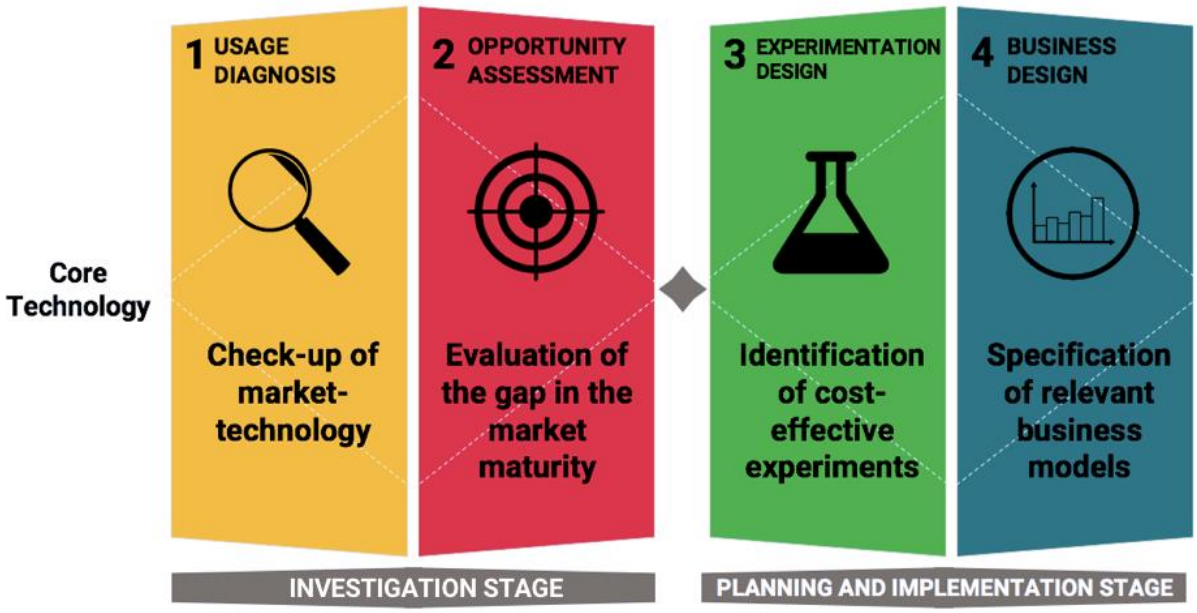


Figure 29. DUE process

To better explain the DUE process, we detail in the following section the application of DUE to the case of a technology-oriented innovative startup. The fourth step of the process is not detailed here, as its description exceeds the scope of this paper.

4.4. Case study: a shape-changing technology

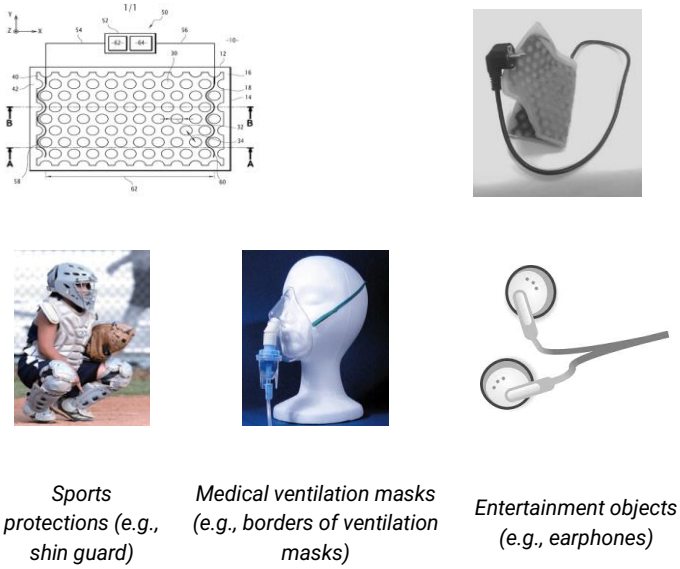
The DUE methodology has been deployed in a startup company that has developed and patented a shape-changing technology (see Figure 30). Due to confidentiality, the name of this company remains non-disclosed.

The technology of this startup is a shape-changing plastic material that becomes flexible when plugged into a source of A/C current. The prototype is almost instantaneously deformable and reversible which makes it convenient to be incorporated into daily objects. The user can adapt the material to an expected shape.

By the time the DUE methodology was applied, the startup had been created for a year and a half and some usages and markets of its technology had already been identified. However, the identification of the latter was merely based on the intuition of the entrepreneurs and their advisors[11] (see Figure 30 for examples where the technology

[11] Innovation advisors of this startup were: the members of its advisory board, its business development coaches at the innovation incubator in which the startup was incubated. These actors had a deep knowledge regarding markets and the existing similar technologies.

can be introduced to improve the shape adaptation of objects such as shin guards, medical ventilation masks, and earphones).



Sports protections (e.g., shin guard) | *Medical ventilation masks (e.g., borders of ventilation masks)* | *Entertainment objects (e.g., earphones)*

Figure 30. Shape-changing technology: a schematic presentation of a section of the prototype (up) and some of the identified usages (bottom)

After a brief discussion with the startup, it seemed that DUE is able to help this startup, because: first, the startup needed to systematically diagnose markets and users, and second, to transform the technology into marketable products, the startup did not know how to prioritize its R&D activities and mainly its resource-intensive experiments.

The DUE process was implemented during two months in this startup and through three collaborative sessions of one to two hours each. In these sessions, the startups' co-founders and its innovation advisors were involved. The goal of these sessions was to provide decisions supports to the startup on relevant experiments to be conducted.

4.4.1. First step of the DUE process: Usage Diagnosis

4.4.1.1. *Building a structured techno-market memory*

The first task in the DUE process consists in creating a memory of what has already been done by the startup company in terms of identifying usages, markets, and also regarding previously conducted experiments, their conditions, cost, time, and results obtained. The startup is therefore asked to respond to a questionnaire containing more than 50 questions (see 4.9.1 for the topics of the questions). The responses to this questionnaire are systematically captured and transferred into *Market-Technology Libraries* and *Experimentation Libraries*. These libraries keep the trace of an important part of the company's R&D activities. They are therefore useful as a first structuring

deliverable for the startup. The format of these libraries can vary according to the startup's needs. But, DUE puts forward graphical and synthetic documents or heuristic maps. The responses to the questionnaire generate a first set of graphical results (such as mind maps) in a manual fashion.

4.4.1.2. *Measuring the relevance of the business model and its components*

The subsequent task consists in evaluating the business assumptions and ideas of the startup by reflecting them into the graphical template of the Business Model Canvas (BMC)[12] (Osterwalder and Pigneur, 2010). This evaluation technique is particularly beneficial, as it allows to better understand how the startup expresses its strategic choices (e.g., its value proposition and identified customer segments), its value network, as well as cost-revenue streams. The BMC-RID technique (see (Bekhradi et al., 2016)) is used here to evaluate and verify the maturity of the UNPCS proofs (standing for Usefulness, Newness, Profitability, Concept, and Stakeholder network). A set of questions based on 30 pieces of evidence supports the task of assessing these proofs.

A primary assessment of the UNPCS proofs by the startup and its advisors shows that the proof of usefulness needs to be improved. This usefulness deficiency is due to the lack of satisfactory solutions to the users'/customers' problems. Besides, these problems are not well-identified and measured. There is therefore need to systematically explore problems by, first, screening a set of usages of the technology, and then characterizing important innovation problems in each usage.

4.4.1.3. *Eliciting and clustering usages of the technology*

Further, to elicit and map the possible usages of the technology, a brainstorming session is organized with the startup and its innovation advisors. The underlying question of this session is: "what are the *activities* in which the technology can serve to solve a *problem of users/customers*?". The result of this session enables to cluster the identified usages into two distinct classes. This clustering is done based on the identification of key activities that have emerged from a primary review of usages. In fact, the technology enables to perform two activities: adapting to the shape of the human body; and adapting to the shape of an object (see Table 7).

[12] The BMC is composed of nine blocks that are : Customer Segments, Value Proposition, Distribution Channels, Customer Relationships, Revenue Streams, Key Activities, Key Resources, Key Partnerships, and Cost Structure. The graphical template of the BMC is widely used by startup companies to describe and share their business assumptions and ideas.

Table 7. Usage categories of the shape-shifting technology

Main activity	Name of the usage category	Number of identified usages	Examples of usages
Adapting to the shape of the human body	***Human Body Interface (HBI)***	66	• Earphones • Shin guards • Shoes
Adapting to the shape of an object	***Embedding and Structuring Objects (ESO)***	20	• Packaging covers • Part of an industrial device or a decoration object

Given the important number of usages to deal with, at this moment of the process the startup must decide about a category or a sub-set of usages to focus on. Thus, the startup decides to focus on the first category that contained 66 usages. The second deliverable of the first step was a synthetic heuristic map containing this class of usages (see 4.9.2).

4.4.1.4. *Exploring Deep Knowledge and developing skills*

Once the usages are identified, the next task of the DUE process deals with a systematic exploration of knowledge and skills with regards to each identified usage of the technology. Several categories of knowledge must be explored. These categories, defined as *Deep Knowledge* (see, e.g., (Lamé et al., 2018; Bekhradi et al., 2017)), consist of:

- frequent usage scenarios;
- important users' problems;
- causes and consequences of these problems;
- more or less effective solutions (and technologies) that exist to deal with these problems;
- users' behaviors and perception of a similar technology;
- lifecycle of similar technologies (see, e.g., Gartner hype cycle or S-curve);
- failure reasons of the similar technologies; and
- existing standards, specifications, and regulations that the technology must comply with.

Different techniques can help with investigating Deep Knowledge. These techniques include among others: user surveys, technology and legal watches, numerical

simulations, and all other technique[13] that enable the company to acquire knowledge and skills about the above-mentioned categories of Deep Knowledge.

In our case study, as the startup decides to focus on the first category of usages, called *human body interface*, there is need to acquire knowledge about how the technology can better adapt to the shape of the human body parts. This knowledge is not necessarily available in the core competencies of the startup as it involves a deep knowledge about multiple disciplines such as physics, healthcare, biology, and human behavior. For instance, a specific know-how in physics, with the calculation of the radius of curvature, and the mechanics of materials is needed. In the case where the focus is to design a shape-changing earphone, the startup must gain knowledge about the human auditory system, anatomy of the ear, and the existing technologies. The startup is therefore encouraged to explore new related knowledge instead of directly building a prototype for adaptable earphones and conducting trials and errors.

Once satisfactory amount of information is collected per each usage, the Dependency and Structure Modeling of Value Bucket (DSM-VB) algorithm of the RID methodology enables to identify promising markets characterized by value buckets. Indeed, the DSM-VB combines, per identified usage, and in several sets of matrices, three dimensions that are *problems*, *usage scenarios*, and *existing solutions*, to compute the poorly or unsolved frequent problems.

4.4.2. Second step of the DUE process: Knowledge Exploration

4.4.2.1. *Identifying and evaluating promising markets*

The second step of the DUE process begins with implementing DSM-VB algorithm. The latter determines the difference between two spaces. The first space includes: important *problems* occurring in frequent *usage scenarios* without considering the existing solutions (see matrix A in Figure 31). The second space includes important *problems*, occurring in frequent *usage scenarios*, that are lowered thanks to the effectiveness of the *existing solutions* (see in Figure 31 matrix D which is the product of C and B). The *uncovered* important and frequent problems are value buckets that represent value creation opportunities of the technology. We characterize a value bucket as a *promising market* in the rest of this study.

13 One may also underline other investigation techniques or sources such as: interviewing lead users (Von Hippel, 1986), questioning domain experts, reviewing scientific literature, reading technical reports and sourcebooks, patent search, exploring databases, and reverse engineering.

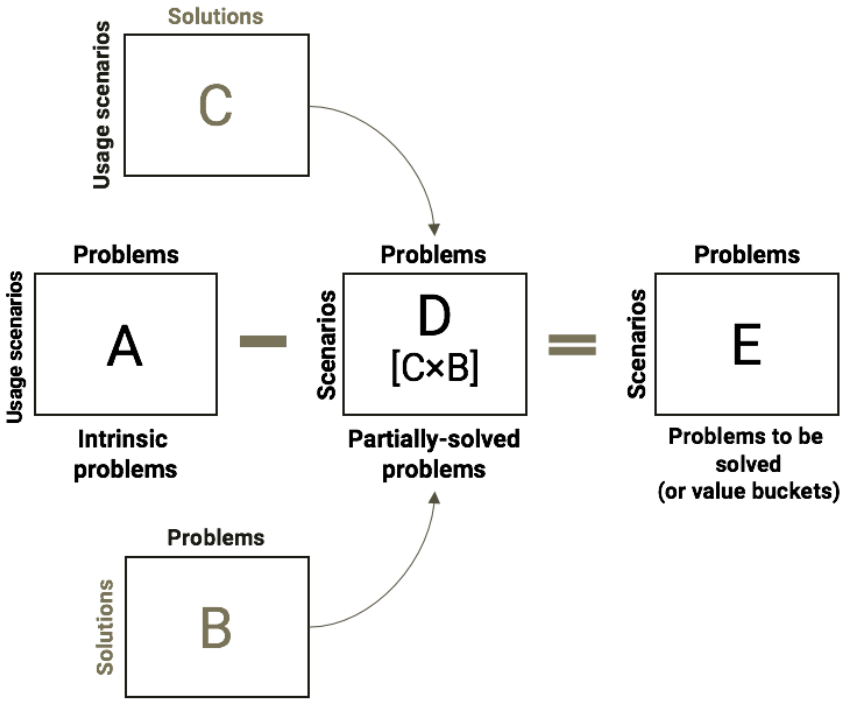


Figure 31. DSM value bucket mechanism

In our case study, 21 value buckets are identified and filtered from the 66 previously-identified usages. These value buckets or promising markets represent valuable information on problems that are worthy of being addressed. For the sake of simplicity, in the rest of this paper we only consider five out of 21 markets. These markets are listed below with their related value bucket expressed as a combination of *problem* occurring in a *usage scenario*:

m_1: cosmetic masks (*poor oil distribution* in the case of *home usages*);
m_2: shin guards (*injury and bone fracture* in *tackle receiving*);
m_3: ski boots (*injury and musculoskeletal disorders* in *long-term use*);
m_4: orthopedic insoles (*time and efficiency loss* in *customizing orthopedic insoles*);
m_5: earphones (*bad fitting in the ears* during *sport and in-movement situations*).

The next task in the DUE process consists in comparing these markets in terms of their attractiveness and potential of economic value creation by assessing the Market Attractiveness Index (MAI). In general, this index is calculated as the weighted average of the MAI parameters. In the list below, the first four parameters are borrowed from the works of (Best, 2012). The following six parameters are adapted and defined in the context of a technology-oriented innovative startup:

- market size: total number of potential customers and companies on this market;

- market potential (or growth): estimated maximum total sales revenue of all suppliers of a product in a market during a certain period;
- ease of entry: startup costs and other obstacles such as competitors, or in other words, entry barriers;
- distribution channel access: degree of easily finding channels and related suppliers to deliver value proposition to customers;
- likelihood of finding investors: probability of easily finding funds in a specific market;
- customer acceptance of a technological innovation: degree of acceptance of the technology regarding its *perceived usefulness* and/or *perceived ease of use* (see, e.g., (Davis, 1989)).

As shown in Figure 32, an intensity scale from 0 to 5 (with 5 as the most important or, for instance, the biggest or a very easily penetrable market) is used to assess the value of each of the six parameters categorized in three classes: market forces, competitive intensity, and market access.

w (between 0 to 1)	0,9	0,9	0,7	0,4	0,8	0,4
	Market forces	Competitive intensity			Market access	
	Market size	Market potential (or, growth)	Ease of entry on the market	Likelihood to find potential investors	Customer acceptance of an innovation	Distribution channel access
m_1 Cosmetic masks	5	5	2	5	4	4
m_2 Shin guards	4	5	3	2	4	4
m_3 Ski boots	3	4	5	4	5	5
m_4 Orthopedic insoles	3	4	3	3	2	4
m_5 Earphones	5	5	1	4	4	4

Figure 32. MAI assessment for the five promising markets

Each value of the MAI matrix is called k_i, where i represents a market. The relative importance of each parameter was then weighted by using a 0 to 1 intensity scale (w). All these values are determined by the startup based on their market studies, and are then validated by the startup's advisors or domain experts. Finally, the weighted average of the values of the six parameters yields the MAI per market (MAI_i):

$$MAI_i = \frac{\sum_{i=1}^{6} \sum_{k=1}^{n} (k_i \times w_k)}{n}. \qquad (1)$$

4.4.2.2. *Characterizing key properties of the technology*

The subsequent task of the process involves an in-depth analysis of the technology through the identification of its underlying properties. As opposed to existing approaches that merely focus on the technical functions or technology affordances (see for instance (Gaver, 1991)), we emphasize the broader concept of usage and the potential of the technology to satisfy usage scenarios, like the mechanism of usage coverage indicator (UCI) already described in (Wang et al., 2013; Yannou, Yvars, et al., 2013). An ontology of technology characterization is proposed in Figure 33.

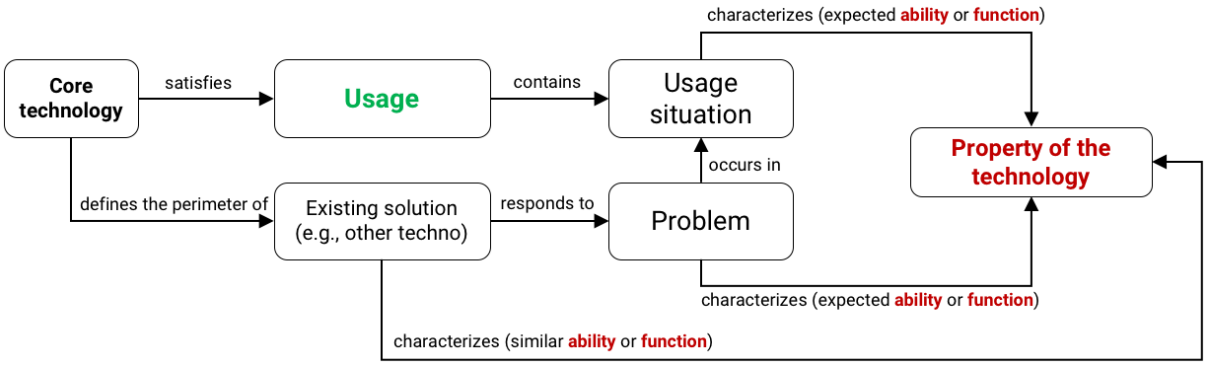


Figure 33. Ontological model to identify the properties of a technology

In this case study, 14 properties of the technology are thoroughly defined (see the complete list in 4.9.3). For the rest of this paper and for the sake of clarity, only three key properties are kept. These properties are:

***p*$_1$**: *ability to cover bony parts of the human body*;
***p*$_2$**: *heat setting*; and
***p*$_3$**: *practicality in terms of volume and portability*.

4.4.2.3. *Measuring the market maturity gap*

The next task consists in combining the identified markets and the properties of the technology in a set of dependency matrices to compute the market maturity gap. An extension of the DSM-VB algorithm is proposed in the DUE process. The mechanism of this new algorithm is very similar to the value bucket algorithm. However, instead of combining problems, usage scenarios, and existing solutions, the new algorithm links the promising markets and the properties of the technology in a set of matrices. The output of the algorithm is the quantified market maturity gap that we may reasonably call meta value bucket as it is fed by value buckets and the new algorithm follows the same mechanism as the DSM-VB. Therefore, we name the proposed algorithm, DSM meta value buckets (DSM-mVB) that includes two main matrices (see Figure 34).

The first matrix (F) expresses the expected or required maturity of the properties of the technology in the promising markets. If the technology reaches this required maturity, it can fulfill a set of conditions enabling it to easily penetrate the market. These requirements could be for instance the threshold level of a given performance at which a successful technology is already released or can be approved for commercialization (as is the case with FDA-regulated medical technologies).

The second matrix reflects the current maturity of the technology (see matrix G in Figure 34). The latter expresses that for the time being the properties of the technology are more or less mature to respond to the requirements in the promising markets. The subtraction of the second matrix from the first one provides a new matrix that contains the intrinsic market maturity gap. The latter must be normalized with regards to the relative importance of the markets and of the properties of the technology. The previously calculated MAI and the average of required maturity of the properties are used to normalize the market maturity gap. Finally, matrix I calculates the normalized market maturity gap.

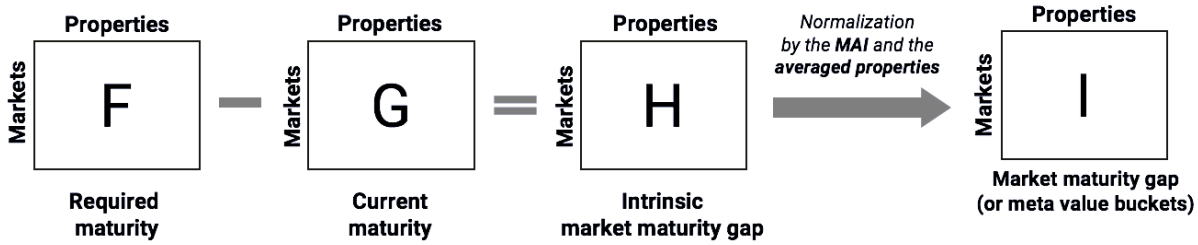


Figure 34. DSM meta value bucket mechanism

The data in each cell of these matrices indicate the importance or the degree of maturity of a given property of the technology in a given market. An intensity scale from 0 to 5 is used here to assess this maturity. If the value is 0, then it means that this property is not relevant at all in this market; if the value is equal to 5, then this property is very important/relevant to the market. The data to complete these matrices are declared by the startup. But, they are verified through other complementary sources: (i) existing standards that a technology must comply with (a literature review of the standards of each market is therefore mandatory); (ii) discussions with different experts who have an extensive knowledge about both markets and technologies; (iii) startup's existing knowledge and experience.

Based on matrix I, a last matrix called "maturity level" (J) is computed. The DSM-mVB algorithm thus determines the degree of the technology maturity in percentage:

$$J_{ij} = 1 - \left(\frac{H_{ij}}{Max_{ij}(H_{ij})} \times \frac{MAI_i}{Max(MAI_i)} \times \frac{\overline{F_j}}{Max(\overline{F_j})}\right), \qquad (2)$$

where $\overline{F_j}$ is the average of the required maturity of the properties of the technology for all markets. In the case where the value of a given cell of this matrix is equal to 100%, it shows that the technology has already reached the required maturity for this property in a given market. If the value is more that 100%, it means that the technology has already surpassed the required maturity level, and that the meta VB (or market maturity gap) is already absorbed. In other words, there is no market maturity gap to be bridged.

Based on the quantified meta VBs, a decision must be made. In our case, the startup decided to first focus on the most challenging meta value buckets, i.e., where the market maturity gaps are the most important. The startup has decided to focus on the following meta VBs ranked from the importance of the market maturity gap:

- ***mVB$_1$*: *ability to cover bony parts of the human body*** in the market of ***ski boots*** (related to the VB: *injury and musculoskeletal disorders* in *long-term use*);
- ***mVB$_2$*: *ability to cover bony parts of the human body*** in the market of ***shin guards*** (related to the VB: *injury and bone fracture* in *tackle receiving*);
- ***mVB$_3$*: *practicality in terms of volume and portability*** in the market of ***earphones*** (related to the VB: *(bad fitting in the ears* during *sport and in-movement situations*).

In another context, the startup could have selected first the least important gap as they would call for less effort in terms of technology improvement (because the properties of the technology are more mature).

The choice and filtering of meta VBs are done according to the startup's strategy, technology development capacity, and fund raising priorities. The chosen sub-set of meta VBs is documented and centralized in a Meta Value Bucket Hub. The role of this hub is to keep a traceability of the market and technology focuses of the startup. In the context of large companies or startups with several departments, this hub enable to efficiently transfer the technology development focuses of the company to other departments/persons in charge of experimentation and business development.

4.4.3. Third step of the DUE process: Experimentation Design

4.4.3.1. *Formulating hypotheses based on the identified market maturity gap*

The selected meta VBs constitute a justified scope for the technology maturation. They also provide rational grounds for hypotheses in experiments.

This step of the DUE process provides seven generic guidelines to better define and express hypotheses of experiments:

- generate hypotheses based on the most important gaps in the market or meta value buckets;
- link each hypothesis to the problem to be solved in a given usage scenario (i.e., to a value bucket);
- make sure that the hypothesized relationships have not yet been tested (by referring to the Experimentation Libraries internally (see 4.4.1.1), or by investigating outside the company);
- postulate hypothesis in the form of a relationship between variables concerned;
- determine whether the hypothesis can be experimented and measured;
- define hypotheses that can be verified, if possible, according to a given threshold;
- avoid combining hypotheses and refine similar hypotheses to merge or to differentiate them.

In our case study, the first hypothesis (η) of the first $\boldsymbol{mVB_1}$ is named $\boldsymbol{\eta_{1,1}}$ and expressed as: "**increasing for two more millimeters the size of the external layer of the product inserted inside the *ski boot* will twice absorb the shock, and will therefore reduce important "*injury and musculoskeletal disorders" in "long-term use"*.**"

4.4.3.2. *Describing experiments in test cards*

Once hypotheses are stated, the "DUE test cards" are proposed to describe the context of experiments. The concept of Test Card is borrowed from the works of (Osterwalder et al., 2015). Here, the classical Test Card is extended to encompass the identified meta value buckets and value buckets.

Each DUE test card (see Figure 35) contains three key information that are: a meta value bucket (mVB), a hypothesis generated based on this mVB, and a specific experimentation action to verify the identified hypothesis. A DUE test card is therefore coded as follows: $\boldsymbol{\eta_{a,b,c,}}$ where ***a*** reflects the meta value bucket number, ***b*** the hypothesis number, and ***c*** the number corresponding to the specific action to be conducted.

Moreover, the DUE test card contains five indicators that are (see Figure 35):

- relative importance of meta value bucket (compared to other identified meta value buckets);

- criticality of the hypothesis (degree to which a generated hypothesis is critical/has priority);
- data reliability (degree to which the results of experiments are reliable);
- financial cost (which includes the cost of designing, building, running and analyzing an experiment); and
- lead-time of experiments (time from the initiation to completion of an experiment).

The value of each variable is estimated by the startup company on a scale of 0 to 5 (with 5 as the most important or the most expensive or time-consuming). The accuracy of the estimated data is then validated by experts and startup's advisors.

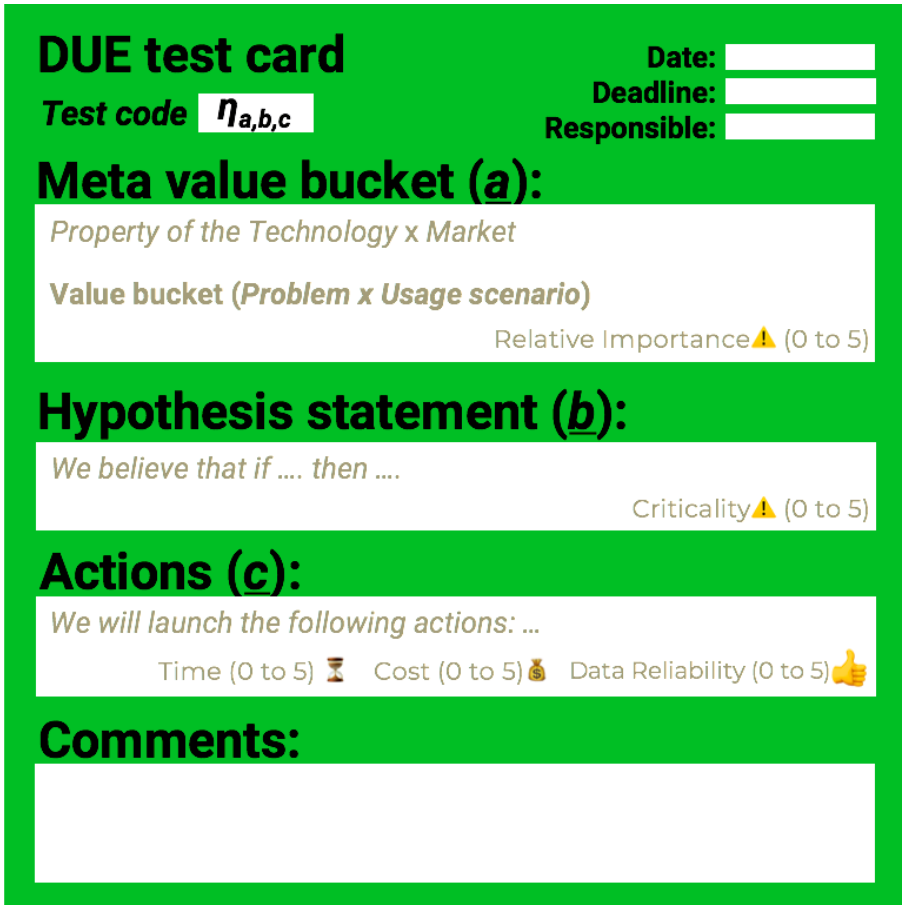


Figure 35. DUE test card

4.4.3.3. *Prioritizing and selecting experiments*

Once several DUE test cards are generated, a decision must be made to focus on one or several experiments. The DUE recommends the choice of those that are the most economical and quickest related to priority meta value buckets. Then, once these experiments are conducted, investments can be steered to more reliable and critical tests.

In our case study, the following experiment ($\eta_{2,2,1}$) is selected by the startup to be conducted because it is the most economical one. This scenario corresponds to:

- the second meta VB (mVB_2):
  - *"**ability to cover bony parts of the human body** in the market of **shin guards,** where there are **injury and bone fracture problems** in the situation of **tackle receiving**";*
- the second hypothesis defined for this mVB:
  - "***twice rigid external layer** applied on the shape shifting part of the shin guard will better protect the tibia bone and consequently **reduce bone fracture by 10%** in the **tackle receiving situations***"; and
- the first set of experimentation actions for the second hypothesis of the second mVB:
  - "***simulating different collisions** on a twice rigid material and **measuring stiffness and damping coefficients of shock absorption on a fragile bone***".

In the above-mentioned experiment, conducting simulations is economical and can be conducted quickly even though the data reliability of the numerical simulation is not high. The identified meta value is ranked as the second most important one and the test hypothesis is not the most important hypothesis.

The forth step of the DUE process is called Business Strategy Design and consists of three tasks: (i) re-measuring the UNPCS proofs in the Business Model Canvas (BMC), (ii) generating new BMCs, and (iii) specifying business and fund-raising roadmaps. As the last step of the DUE process requires some preliminary results of experiments, this step is not detailed here as it exceeds the scope of this paper.

A summary of the three first steps of the DUE process as well as the DUE data collection and validation mechanism are detailed in the following section.

4.5. DUE in summary: a rigorous methodology to structure and organize R&D activities

4.5.1. Detailed process of DUE

Each step of the DUE process is a flow of organized tasks that delivers intermediary and final results. These organized tasks enable to reduce costly and time-consuming back-loops. Indeed, each deliverable or tool of the DUE considered as a function with an input and an expected output. The outputs of each step cascade into the process to reach a rational experimentation strategy. The detailed steps of the DUE process including 13 functions/tasks are presented in Figure 36.

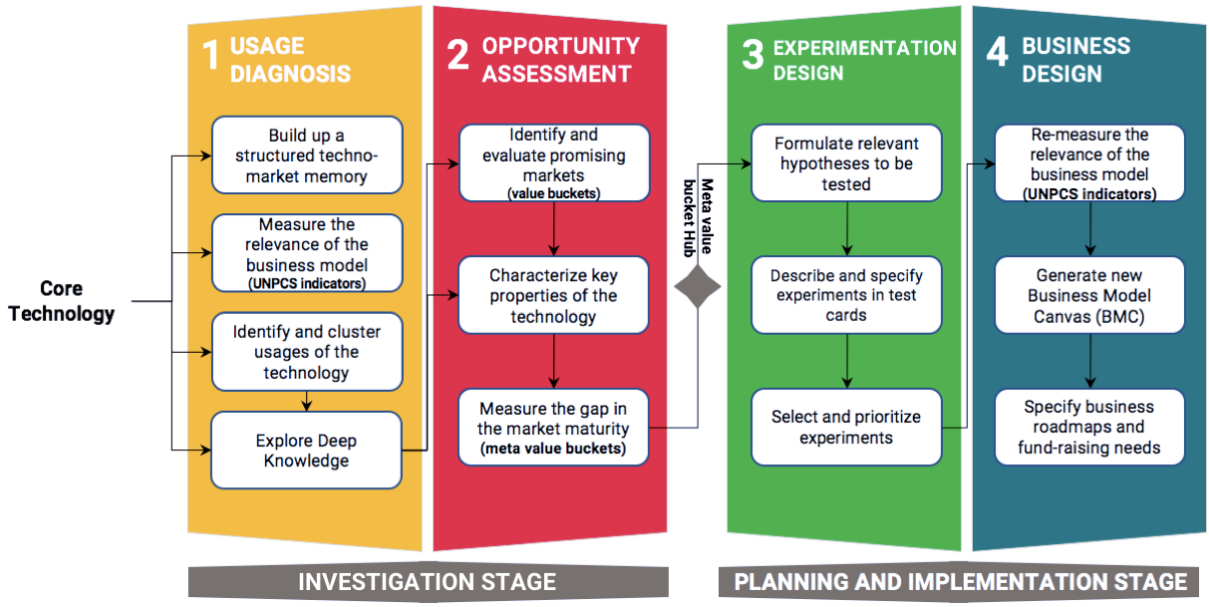


Figure 36. Detailed steps of the DUE process

The structured process of the DUE methodology contributes to organizing the R&D activities of a company. In the context of innovative startups, an important part of their investments in R&D activities are devoted to experimentation[14]. Therefore, the effectiveness of these experiments is challenging for startups dealing with limited time and resources. To address this challenge, the DUE process, prior to running experiments, dedicates more attention to the investigation of problems to be solved, and to the weaknesses of the technology to be improved.

Then, the experimentation design step of the DUE process aims at defining relevant experiments based on a selection of the market maturity gaps (called meta value buckets). These gaps constitute a relevant ground for systematically formulating the hypothesis of experiments.

4.5.2. DUE: Data collection and verification process

The data used in the DUE process are collected from different sources such as review of the existing documents on usages and technologies by referring to (Market-Technology Libraries), startup previous experiments and obtained results (by referring to Experimentation Libraries), agile-rapid micro-tests to capture data for future tests,

[14] The literature in entrepreneurship and innovation management emphasizes that experimentation is the most important R&D activity of technology-oriented innovative startups (see for instance (Kerr et al., 2014; Blank, 2013a; Ries, 2011)). In general, testing activities (or experiments) counts for more than 50% of companies R&D expenditures (see for instance (Bertolino, 2007)), and more than 75% of their R&D time (see (Allen, 1966)).

observations of usage situations, interviews with users and domain experts, as well as a set of heuristics based on entrepreneurs' intuition following brainstorming sessions.

All the above-mentioned elements are confirmed by innovation experts that are startups' advisors and mentors with a solid knowledge of different markets and technologies. Especially, they play a key role in verifying the significance of the declared data by the startup in a second round of data verification. The first round of data verification is done internally and according to investigations made by entrepreneurs. Moreover, the accuracy of the collected data (necessary mainly for establishing the 0 to 5 intensity scales) is not an issue in the DUE methodology, since the relative importance of the matrices and meta value buckets matters rather than their intrinsic values.

4.6. Discussions

The DUE methodology is built after identifying lacks in the existing design and testing approaches. Our literature review shows that the popular design and creativity methods have some shortcomings when it comes to make a technology mature for addressing its promising markets. DUE provides some answers to these shortcoming by systematically exploring usage scenarios, problems as well as the properties of a technology. In this context, DUE borrows the important concepts of value bucket from the Radical Innovation Design® methodology.

DUE provides a structured process along with organized steps and deliverables unlike the loop-based and so-called non-linear process of Design Thinking (DT) (Brown, 2009). Compared to DT, DUE questions the relevance of an innovation problem with a thorough analysis of usage situations and value buckets before prototyping and testing.

The same lacks are observable in the context of The Lean Startup (TLS) approach (Ries, 2011). TLS advocates building MVPs (minimum viable products) and testing them in a loop-based fashion, whereas DUE dedicates more time and effort to evaluate areas where it is worth marshalling resources to develop and experiment a technology before building an MVP. Hence, the DUE process falls within a set-based approach that begins with exploring from the front end of innovation to progressively reduce uncertainties.

DUE is a hybridization of several methods and tools, among them we can mention the testing part of the VPD approach (Osterwalder et al., 2015), where Test Cards are a powerful tool to structure the testing activity. However, the hypotheses extraction step of VPD is merely based on the assumptions made in the BMC, Value, and Customer

Profile maps. The quantification of meta value buckets in the DUE process provides justified grounds for formulating and prioritizing relevant hypothesis.

Based on the above-mentioned comparisons, DUE is a differentiating methodology to organize and structure testing in a company (see Figure 37).

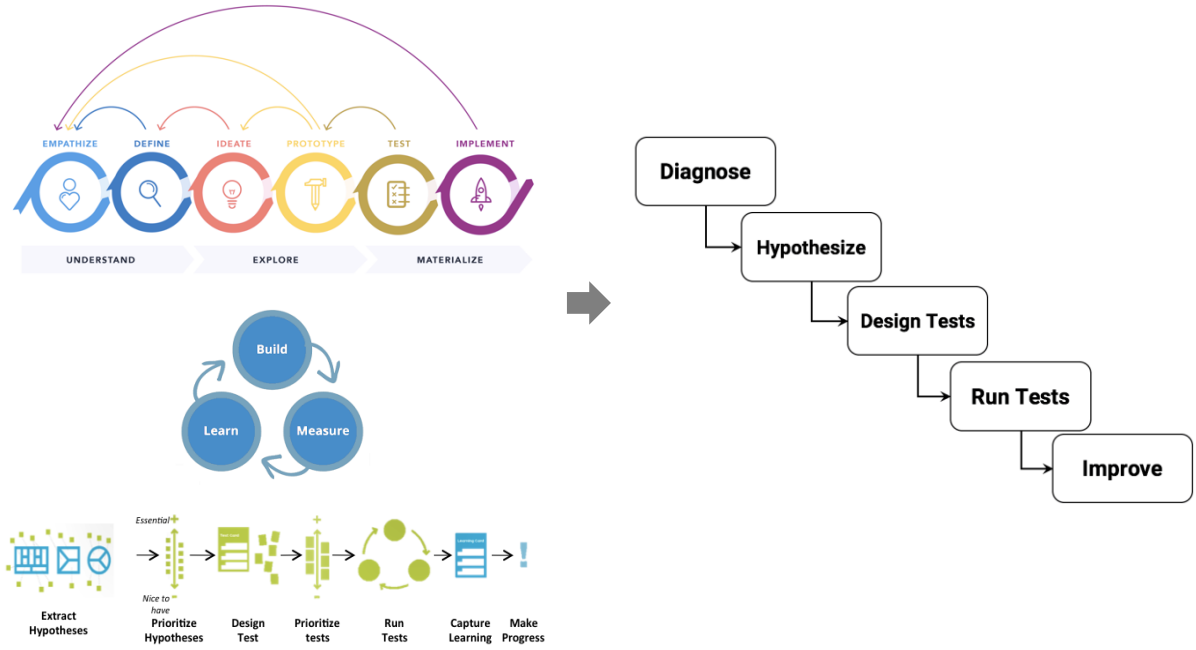


Figure 37. From conventional loop-based testing processes (such as the process of Design Thinking (up left), TLS' Build-Measure-Learn loops (left middle), and testing of the VPD (bottom left)) to a more structured experimentation process (right)

Although, the DUE methodology in its current form provides important guidelines, authors are also aware of its limitations. First of all, the listing of usages and properties of the technology is supported by structured brainstorming sessions and tools. However, the comprehensiveness of these lists might be questionable. There is therefore need to set other complementary indicators and threshold levels to decide about the exhaustiveness of the identified usages and properties of the technology.

Another limitation concerns the choice of cost-effective experiments which is done manually for the time being. A multi-objective optimization could be relevant to identify tradeoffs and Pareto-optimal experiments. However, such an optimization model must be fed with a more important set of data and not merely with few examples. Our future work will further address the optimization issue.

The principal implication of the DUE methodology is the change of the mainstream R&D practices of startups which consists in "*Just launch a prototype, then let's see*". This vision is less adapted to the context of limited time and resources of technology

startups and especially when they are mostly funded by public funds (e.g., in France two third of innovation-related funds are from public sources (Ezratty, 2018)). There is thus a crucial need to allocate resources to those R&D activities and mainly those experiments that enable to increase the likelihood of success, instead of verifying uncertain hypotheses. DUE takes a step forward to avoid wastes and to secure the launch of an innovation.

4.7. Conclusion and perspectives

Given their limited time and resources, technology-oriented innovative startups cannot rely on random, loop-based and consequently costly trials. The DUE (Design by Usage-based Experimentation) methodology tackles this issue by: (i) screening usages to elicit a list of promising markets characterized as value buckets (i.e., important problems occurring in frequent usage scenarios for which the existing solutions are not efficient) (Yannou et al., 2016; Lamé et al., 2017), (ii) identifying the main properties of the technology, (iii) linking the identified promising market (or value buckets) to the properties of the technology in order to assess meta value buckets (or those properties that must be improved, through experiments, for the most promising markets), and at (iv) identifying the prioritizing effective experiments.

The DUE methodology has been applied to the case of a shape-changing technology developed and patented by a startup in France. The results were new and useful for the startup, as they have provided a structured way of specifying experiments. The startup company used the results of this case study to consolidate its file for an innovation prize competition.

Two other case studies of the DUE methodology have been conducted with two other technology startups in Montreal, Canada. The results are currently under process and will enable to make DUE more mature. Authors hope that these results further encourage the academic discussion on the topic of experimentation in the context of startups.

Our further work will focus on two objectives. First, automatizing the generation of the Market-Technology Libraries with the help of deep learning algorithms. Indeed, the internal and external information (regarding the R&D, markets, other technologies etc.) can be automatically screened to improve the quality of the value buckets and meta value buckets. Therefore, in our future work we intend to develop a deep learning algorithm that effectively collect information and help develop company's skills and core competencies. Moreover, deep learning must enable to visualize the collected information and data in a synthetic and graphical manner (e.g., with automatically-generated heuristic maps, infographics, charts). Second, the identification of cost-

effective experiments is done manually in the current version of the DUE methodology. In our work, we will identify and detect the Pareto-optimal testing activities.

4.8. References

Akao, Y., King, B., and Mazur, G. H. (1990). *Quality function deployment: integrating customer requirements into product design* (Vol. 21): Productivity press Cambridge, MA.

Allen, T. J. (1966). Studies of the problem-solving process in engineering design. *IEEE Transactions on Engineering Management*(2), 72-83.

Babuska, I., and Oden, J. T. (2004). Verification and validation in computational engineering and science: basic concepts. *Computer Methods in Applied Mechanics and Engineering, 193*(36), 4057-4066.

Bekhradi, A., Yannou, B., and Cluzel, F. (2016). *Importance of problem setting before developing a business model canvas.* Paper presented at the DESIGN 2016 14th International Design Conference.

Bekhradi, A., Yannou, B., Cluzel, F., and Vallette, T. (2017). *Categorizing user pains, usage situations and existing solutions in front end of innovation: The case of smart lighting project.* Paper presented at the The 21st International Conference on Engineering Design, ICED17, Vancouver, British Columbia, Canada. August 21-25.

Bertolino, A. (2007). *Software testing research: Achievements, challenges, dreams.* Paper presented at the 2007 Future of Software Engineering.

Best, R. (2012). *Market-based management*: Pearson Higher Ed. 9780133071627.

Blank, S. (2013a). *The four steps to the epiphany: successful strategies for products that win*. New Jersey, United States: BookBaby. 0989200523.

Blank, S. (2013b). Why the lean start-up changes everything. *Harvard business review, 91*(5), 63-72.

Brown, T. (2009). *Change by design: How Design Thinking Transforms Organizations and Inspires Innovation*. New York, United States: HarperBusiness.

Cascini, G., Rissone, P., Rotini, F., and Russo, D. (2011). Systematic design through the integration of TRIZ and optimization tools. *Procedia Engineering, 9*, 674-679.

Cascini, G., Rotini, F., and Russo, D. (2009). *Functional modeling for TRIZ-based evolutionary analyses.* Paper presented at the DS 58-5: Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 5, Design Methods and Tools (pt. 1), Palo Alto, CA, USA, 24.-27.08. 2009.

Clarysse, B., and Kiefer, S. (2011). *The Smart Entrepreneur: How to Build for a Successful Business*: Elliott & Thompson. 1904027881.

Cooper, R. G. (1990). Stage-gate systems: a new tool for managing new products. *Business horizons, 33*(3), 44-54.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.

DesignCouncil. (2005). The 'double diamond' design process model. *Design Council*. Retrieved from: https://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond. Access date: July 2018.

Eppinger, S. D., and Ulrich, K. T. (1995). Product design and development.

Ezratty, O. (2018, April 2018). Guide des Startups en France. Retrieved from: http://www.oezratty.net/wordpress/wp-content/themes/Ezratty5/fd.php?file=/Files/Publications/Guide%20des%20Startups%20en%20France%20Olivier%20Ezratty%20Apr2018.pdf. Access date: July 2018.

Fisher, R. A. (1937). *The design of experiments*: Oliver And Boyd; Edinburgh; London.

Frederiksen, D. L., and Brem, A. (2017). How do entrepreneurs think they create value? A scientific reflection of Eric Ries' Lean Startup approach. *International Entrepreneurship and Management Journal, 13*(1), 169-189.

Gaver, W. W. (1991). *Technology affordances*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

George, M. (2002). Lean six sigma: combining six sigma quality with Lean production speed, combining six sigma quality with Lean production speed: McGraw Hill Professional.

Gibbons, S. (2016). Design Thinking 101. Retrieved from: https://www.nngroup.com/articles/design-thinking/. Access date: July 2018.

Hatchuel, A., and Weil, B. (2009). CK design theory: an advanced formulation. *Research in engineering design, 19*(4), 181.

He, L., Chen, W., Hoyle, C., and Yannou, B. (2012). Choice Modeling for Usage Context-Based Design. *Journal of Mechanical Design, 134*(3), 031007-031007-031011. doi:10.1115/1.4005860

Jaruzelski, B., Staak, V., and Shinozak, A. (2016, Winter 2016). Global Innovation 1000 : Software-as-a-Catalyst, The world's largest innovators are shifting the focus of their R&D investments from products to programming. *strategy+business*.

Johansson-Sköldberg, U., Woodilla, J., and Çetinkaya, M. (2013). Design thinking: past, present and possible futures. *Creativity and Innovation Management, 22*(2), 121-146.

Kass, R. A. (2008). Tests and Experiments: Similarities and Differences. *International Test and Evaluation Association, 29*, 294–300.

Kennedy, M. (2008). *Ready, set, dominate: implement Toyota's set-based learning for developing products and nobody can catch you*: Oaklea Press. 1892538407.

Kerr, W. R., Nanda, R., and Rhodes-Kropf, M. (2014). Entrepreneurship as experimentation. *Journal of Economic Perspectives, 28*(3), 25-48.

Lamé, G., Leroy, Y., and Yannou, B. (2017). Ecodesign tools in the construction sector: Analyzing usage inadequacies with designers' needs. *Journal of cleaner production, 148*, 60-72.

Lamé, G., Yannou, B., and Cluzel, F. (2018). *Analyzing RID Methodology through the Lens of Innovative Abduction.* Paper presented at the 15th International Design Conference.

Nobel, C. (2011). Teaching a 'Lean Startup'Strategy. *HBS Working Knowledge*, 1-2.

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey, United States: Wiley. 9780470901038.

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., and Papadakos, T. (2015). *Value Proposition Design: How to Create Products and Services Customers Want*. New Jersey, United States: Wiley. 9781118968055.

Pahl, G., and Beitz, W. (2013). *Engineering design: a systematic approach*: Springer Science & Business Media. 1447135814.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

Snyder, C. (2003). *Paper prototyping: The fast and easy way to design and refine user interfaces*: Morgan Kaufmann. 1558608702.

Sobek, D. K., Ward, A. C., and Liker, J. K. (1999). Toyota's principles of set-based concurrent engineering. *Sloan management review, 40*(2), 67.

Suh, N. P. (2001). Axiomatic design: Advances and applications (the oxford series on advanced manufacturing).

Thomke, S., and Manzi, J. (2014). The discipline of business experimentation. *Harvard business review, 92*(12), 17.

Thomke, S. H. (2003). *Experimentation matters: unlocking the potential of new technologies for innovation*: Harvard Business Press. 1578517508.

Ulrich, K., and Eppinger, S. (2015). *Product design and development*: McGraw-Hill Higher Education. 1259297136.

Vinck, D., and Jeantet, A. (1995). Mediating and commissioning objects in the sociotechnical process of product design: a conceptual approach: Directorate General Science, R&D.

Von Hippel, E. (1986). Lead users: a source of novel product concepts. *Management Science, 32*(7), 791-805.

Wang, J., Yannou, B., Alizon, F., and Yvars, P.-A. (2013). A usage coverage-based approach for assessing product family design. *Engineering With Computers, 29*(4), 449-465.

Wu, J. J., and Atkinson, R. (2017, November 2017). How Technology-Based Start-Ups Support US Economic Growth. Retrieved from: https:// http://www2.itif.org/2017-technology-based-start-ups.pdf. Access date: July 2018.

Yannou, B., Cluzel, F., and Farel, R. (2016). Capturing the relevant problems leading to pain and usage driven innovations: the DSM Value Bucket algorithm. *Concurrent Engineering: Research and Applications*, 1 - 16. doi:10.1177/1063293x16666311

Yannou, B., Jankovic, M., Leroy, Y., and Kremer, G. E. O. (2013). Observations from radical innovation projects considering the company context. *Journal of Mechanical Design, 135*(2), 021005.

Yannou, B., Lamé, G., and Cluzel, F. (2018). *Adapting the FBS model of designing for usage-driven innovation processes.* Paper presented at the IDETC/CIE 2018: International Design Engineering Technical Conferences/CIE: Computers and Information in Engineering, Montreal, Canada. August 2018.

Yannou, B., Yvars, P.-A., Hoyle, C., and Chen, W. (2013). Set-based design by simulation of usage scenario coverage. *Journal of Engineering Design, 24*(8), 575-603.

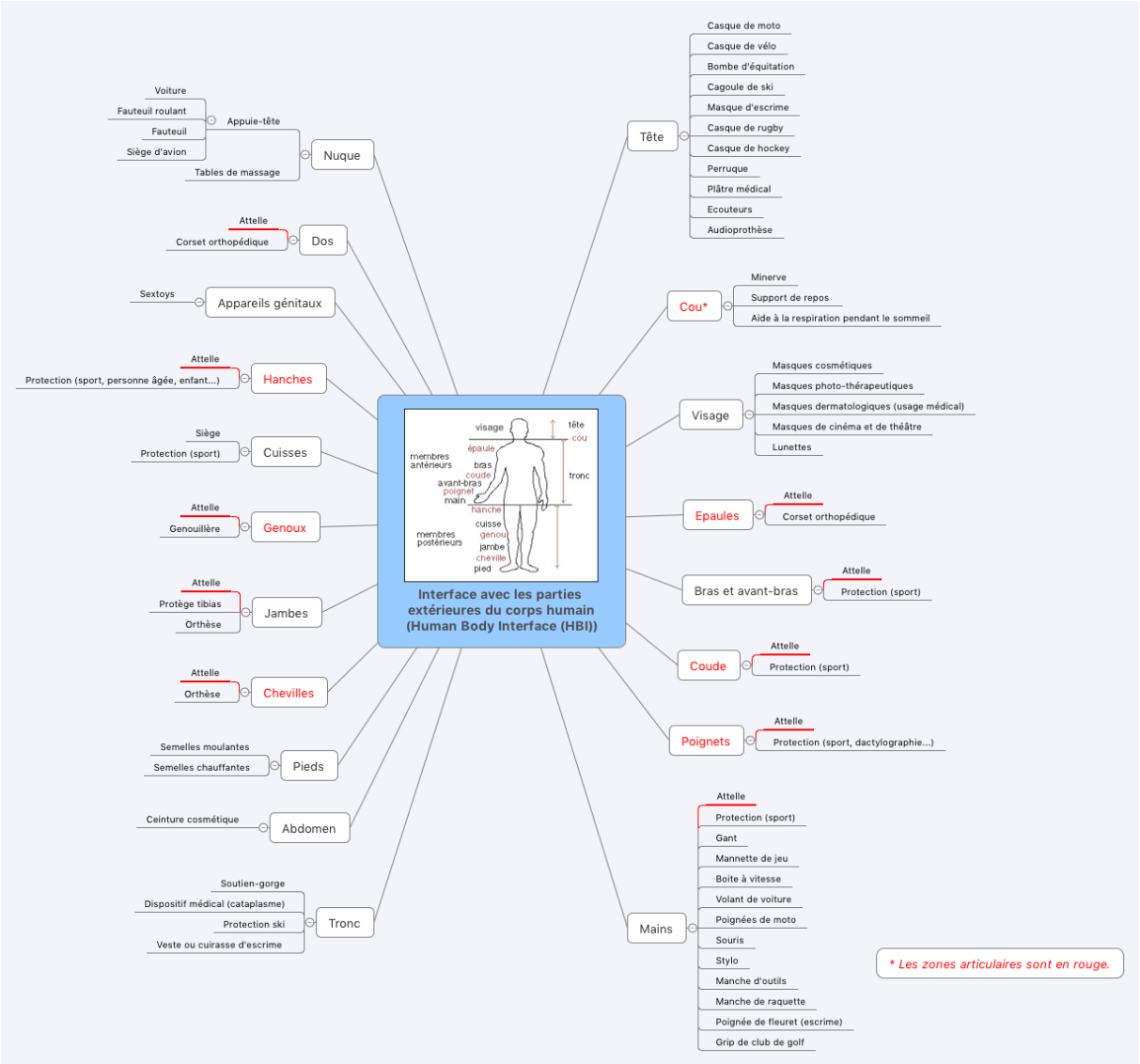
4.9. Appendices

4.9.1. Appendix 1. Topics of the market-technology questionnaire of DUE

R&D activities	
R&D general activities (except from experimentation)	Design and development of new products (innovation methods/tools already used)
	Basic research activities
	Applied research activities
	Research of new applications for existing products
	Improvement of manufacturing or production technologies
	Methods/tools of production management and tools
	Actions to reduce waste and by-products
	Design and development of scaled-up manufacturing processes
	Design and ergonomic issues
	Research to receive certifications, patents and/or licenses
	Open innovation mechanisms (partnership…)
Experimentation	Motivations and reasons for deploying such an experiment
	Methods and tools of testing
	Hypotheses to be tested
	Protocols
	Observation and evaluation techniques
	Involved actors
	Constraints
	Difficulties to conduct this experiment
	Obtained results
Usages of the technology	
Usages of the technology	List of the already identified usages and use-cases of the technology
	Focus on particular usages more than others
	Reasons and motivations for focusing on a particular usage
	Main activities that the technology enables to perform (e.g., improving, optimizing something)
	Usages of similar technologies
	Possible users
	Usage patterns (i.e., the way of using a technology by users)
	Usage scenarios (i.e., archetypal stories explaining a given situation)
	Common denominators of activities/usages
Deep Knowledge	
Deep Knowledge categories	Frequent usage scenarios (incl. data about users, demographics
	Important users' problems
	Causes and consequences of these problems
	More or less effective solutions (and technologies) that exist to deal with these problems
	Users' behaviors and perception of a similar technology
	Lifecycle of similar technologies (see, e.g., Gartner chart and S-curve);
	Failure reasons of the similar technologies, their causes and consequences
	Existing standards, specifications, and regulations that the technology must comply with
Market analysis	
Previous market studies	Existing documents
	Market segmentation and its logic
	Positioning on the market
	Mapping of the environment and strategic analysis (SWOT, PESTEL...)
	Barriers to entry
	Analysis of growth drivers
	Market size
Business model	
BMC components	Value offer
	Customer segments
	Key partners
	Key activities
	Key resources
	Cost structure
	Revenue streams
	Customer relationships

	Distribution and sales channels

4.9.2. Appendix 2. Human Body Interface (HBI) usage category



4.9.3. Appendix 3. Identified properties of the shape-changing technology

No.	Properties of the technology	Definition
1	**Ability to cover bony parts of the human body**	Covering surfaces with direct contact with bones (e.g., cheek, back of head, forehead, hip, leg…) through a rigid contact surface in order to protect the body from external shocks or dangerous movements.
2	**Ability to cover non-pliable parts of the human body**	Covering non-articular parts of the human body (e.g., face, abdomen, dorsum…) in order to adapt their morphology.
3	**Ability to cover pliable parts of the human body**	Covering articular parts of the human body (elbow, wrist, shoulder…) in order to take the form of its pliable parts.
4	**Ability to immobilize parts of the human body**	Immobilizing pliable or non-pliable parts of the human body after a fracture or accident to avoid medical disorders or, to fix a part of the human body for specific medical interventions (e.g., surgery, radiology…).
5	**Ability to vary the thickness of the deformable surface**	Variability in terms of thickness of the surface to be adaptable to desired usage situations (without harming other abilities) (e.g., some parts of the covered surface need to be protected with a thicker deformable surface).
6	**Acceptability for a long-term contact with the skin**	Quality of the used materials that must not cause allergies or cutaneous problems.
7	**Adaptation to complex and polygonal surfaces**	Adapting to the form of a surface with complex and/or variable geometry (e.g., on the surface of the human body or objects in contact with the body), i.e., being polymorphic in order to cover polygonal surfaces and being ergonomic.
8	**Capacity of shifting from a shape to another**	Shifting from different shapes to others from the initial state (i.e., reversibility) to be able to build multiple forms from a current state.
9	**Hardness of the deformable surface**	Degree of rigidity of the deformable surface to resist to shocks or to immobilize in a satisfying way.
10	**Homogenous deformation on the deformable surface**	Degree of homogeneity on the whole surface to guarantee a coherent coverage.
11	**Possibility of the heat setting (thermal comfort)**	Possibility to control the heat degree and its duration to obtain an ideal thermal comfort.
12	**Practicality in terms of volume and portability**	Degree of importance of considering product's weight in different usage situations mainly if carried on the body.
13	**Reliability of materials for multiple shape shifting**	Degree of robustness of the used materials in order to resist multiple shape shifting in different usage situations depending on the number of deformations/formations and desired geometries before becoming obsolete.
14	**Speed of shape shifting**	Time needed to switch between different forms until becoming rigid enough.

Chapter 5. Paper #5: Optimizing R&D activities for technology maturation: proposition of the RITHM (Roadmapping Investments in TecHnology and Markets) methodology

This paper is submitted to the Journal of International Entrepreneurship and Management Journal in November 2018, under the following reference:

- Bekhradi, A, Yannou, B., and Cluzel, F. (2018). Optimizing R&D activities for technology maturation: proposition of the RITHM (Roadmapping Investments in TecHnology and Markets) methodology, *Submitted to International Entrepreneurship and Management Journal*.

The conference paper which provides the basis of this paper is:

- Bekhradi, A., Yannou, B., Cluzel, F., and Kokkolaras, M. (2018). Decision support for R&D activities of innovative technologies. IDETC/CIE 2018: International Design Engineering Technical Conferences/CIE: Computers and Information in Engineering, Quebec, Canada, August 2018.

Foreword

Through the four previous chapters of this dissertation, we have observed that time and resources are limited in the context of startups. Moreover, there is no clear method to enable startups carefully allocating their resources to those R&D activities that are worthy to be conducted.

Chapter 4 was a first attempt to organize the experimentation process of technology-oriented innovative startups. To provide startups with further quantitative decision supports for planning and rationally allocating their investments, a new methodology called Roadmapping Investments in TecHnology and Markets (RITHM) is proposed in this chapter.

It is worth noting that the proposed methodology in the previous chapter is independent from the one presented in this chapter. However, they share common concepts and some deliverables.

The RITHM methodology not only covers testing activities, but also any kind of R&D activities that share common characteristics with testing activities.

Abstract: R&D activities of technology-based startups are often costly, time-consuming, and, above all, not well organized. A review of the literature shows that existing methods and techniques are either oriented towards loop-based experiments or focused on technology forecasting and roadmapping that are not necessarily adapted to startup companies. There is therefore a need for practical tools to structure and optimize R&D activities of technology-based startups. Based on these observations, this paper introduces a new quantitative methodology called RITHM (Roadmapping Investments in TecHnology and Markets) which includes a set of practical yet rigorous tools. This process enables startups to organize their R&D activities and reach, with a moderate effort, adequate maturity level of their technology for the most promising markets. An optimization model provided at the end of RITHM process captures these cost-effective activities. The case of a shape-changing technology is studied in this paper to illustrate the application of RITHM and the decision supports that allow better roadmapping investments in technology and business maturation. The implications of the results are discussed for both entrepreneurial ecosystems and academics.

Keywords: technology-based startup, core technology, R&D activity, testing activity, maturity, planning, roadmapping.

RITHM: Nomenclature

The following nomenclature lists the main terms used in this paper:

Symbol	Definition
U	Usages of the core technology
VB	Value Bucket (frequent painful usage situations for which existing solutions are poor or not at all efficient). A VB is considered as a Market (M) to be targeted.
DSM	Dependency and Structure Modeling

m-VB	Meta-Value Bucket
g_M	Market maturity gap
EOSA	Environment, Operator, Strategy, and Artifact of a test
a	Testing activity composed of the modalities of EOSA variables
C	Financial cost of a testing activity (in euros)
T	Lead-time of a testing activity (in months)
e_{IR}	Expected Improvement Rate of a given testing activity
B	Available Budget of the startup
T_A	Estimated available Time
MVE	Minimum Viable Experiment
MVEP	Minimum Viable Experiment Platform

5.1. Introduction

The technology-intensive and competitive environment of startup companies brings the question of the effectiveness of their R&D activities at the core of their challenges. The number of technology-based startups surged to 47% in the last decade in the US (Wu and Atkinson, 2017). These startups evolve in a highly R&D-intensive environment, since they have a core technology (most often innovative) to maturate and commercialize in the form of several marketable products (Deeds, 2001).

From the product development perspective, several R&D activities at the scale of technology-oriented innovative startups are conducted with the purpose of developing the technology and embedding it into product-service value offers, while reducing inherent uncertainties and risks. Among these R&D activities, testing activities (or experiments[15]) are fundamental to this category of startups (Kerr et al., 2014; Blank, 2013; Ries, 2011), and reflect their major R&D activities (Moogk, 2012). However, technology startups rely most often on loop-based and random experiments without necessarily organizing, nor planning their testing activities (Bekhradi et al., 2018; Bekhradi et al., 2015). Besides, such experiments are costly and time-consuming, and their rationale and efficacy may become questionable.

Given the expansion of technology startups, and the challenges related to their R&D and mainly testing activities, there is a crucial need to structure and plan these

[15] We use in this paper *testing activity* and *experiment* interchangeably. (Kass, 2008) argues that while notable differences are evident between the two notions, overall similarities are more significant than differences.

activities so that they contribute to maturing and fine-tuning a technology for its potential markets. These challenges lead us to explore related literature which lie on the boundary of disciplines such as engineering design, technology management, and innovation management. A primary literature review showed that there is need to carry out systematic investigation about users and their problems prior to the launch of costly and random experiments. Besides, it is necessary, even mandatory, to define optimal testing activities, given the startup's short-term development cycles and limited resources.

Based on this primary review of the literature, it is reasonable to articulate the following question: **what are the most cost-effective testing activities and their short-term planning that enable a technology-oriented innovative startup to improve the maturity of its technology and meeting the promising markets?**

Seeking reliable answers to this question is the objective of our work. To do so, this paper introduces a methodology, called RITHM standing for Roadmapping Investments in TecHnology and Markets, which aims at providing quantitative decision-making supports. The process of RITHM consists in first screening the set of potential usages of the technology by systematically investigating unsolved or poorly-solved problems of users in these usages. In parallel, the process identifies the main properties of the technology to be improved through R&D and testing activities. Then, the process quantifies the techno-marketing gaps that a startup must bridge. Subsequently, a link is established between testing activities and their cost and time as well as their ability to bridge the identified gaps. Finally, three optimization models are proposed to identify the set of testing activities so that they result in the definition of a technology with properties that are mature enough to approach or meet the most profitable markets. Based on these results, relevant decision-making support is provided to startups, so they can define effective technology and market roadmaps.

The RITHM methodology is applied to the case of a shape-changing startup. The final results of this research have contributed to steering R&D investment of this startup. The latter appreciated the structuring process of RITHM and declared a change in its R&D organization, and a reduction in its waste of resources.

The rest of this paper is structured as follows. In Section 5.2, we review the literature related to monitoring and planning both R&D activities in general, and testing activities in particular. In Sections 5.3 and 5.4, we present the RITHM methodology as a new quantitative method to monitor the R&D of technology-oriented innovative startups. The application of the RITHM methodology is illustrated through a case study in Sections 5.5 to 5.9. Section 5.10 details the process of data feeding and validation of the quantitative models. Finally, we discuss implications of the proposed methodology as well as its further developments.

5.2. Related research works

Because this research features organizing and structuring R&D activities, we have concentrated our review of the related works on the R&D activities pertaining to which decisions should be made. Furthermore, due to the existence of very few research works dealing with this topic in the context of technology-oriented innovative startups, the following review focuses on methods and tools that may be used in the context of startups.

5.2.1. Monitoring and roadmapping R&D activities

Research and Development (R&D) refers to activities undertaken by companies or other organizations in developing new product-service systems (PSS), or in improving the existing ones. Frascati manual defines these activities as: "*the sum of actions deliberately undertaken by R&D performers in order to generate new knowledge*" (OECD, 2015). According to this manual, an R&D activity must fulfill five criteria (novel, creative, uncertain, systematic, and transferable). This standardized definition of R&D is relevant as a reference definition. However, this definition deals with R&D projects at the macro scale of national or international projects with, most often, multiple partners.

At the scale of startup firms, some research works (see, e.g., (Astebro, 2004; Shane and Ulrich, 2004; Joglekar and Levesque, 2009)) concentrate on the link between the marketing and R&D functions. For instance, (Joglekar and Levesque, 2009) explore the dynamics in cases in which decisions on when to raise capital are linked to the need to balance capital costs and the desire to maximize the venture's market value. Most of these research works are grounded in entrepreneurship economics, project management, and policy making. Even though they provide useful insights on the determinants of R&D functions, they lack in providing guidelines to startups enabling them to allocate their R&D resources to both technology and market development.

In this respect, the literature of technology and product management can provide some practical supports. For instance, technology forecasting is a discipline that provides some support by using forecasting principles to the dynamic behavior of technology and innovation. This discipline is usually practiced by scholars and by specialist consultants. Several methods such as Delphi method, forecast by analogy, and S-curves are the commonly methods of technology forecasting.

Compatible with the technology forecasting principles, technology roadmapping (TRM) supports "technology management and planning, especially for exploring and communicating the dynamic linkages between technological resources,

organizational objectives and the changing environment" (Phaal et al., 2004). A technology roadmap allows having a compact and comprehensive view of the way with which results from "upstream" R&D activities will feed into "downstream" projects (Cantamessa and Montagna, 2016). These roadmaps can take various specific forms, but generally comprise a time-based chart along with a multi-layer representation. A fictitious example of such roadmaps is illustrated in Figure 38. Other layouts such as flowchart diagrams, trees, and matrices can also be used to outline a technology roadmap.

As shown in Figure 38, a technology roadmap can be studied following a "technology-push" or a "demand pull" approach. The technology-push approach ensures that upstream results can be used by downstream activities. Conversely, from a "demand-pull" perspective, one must verify that the needs emerging from the market are appropriately addressed by the upstream activities and at the right time. In practice, roadmapping will be carried out by iterating the two approaches.

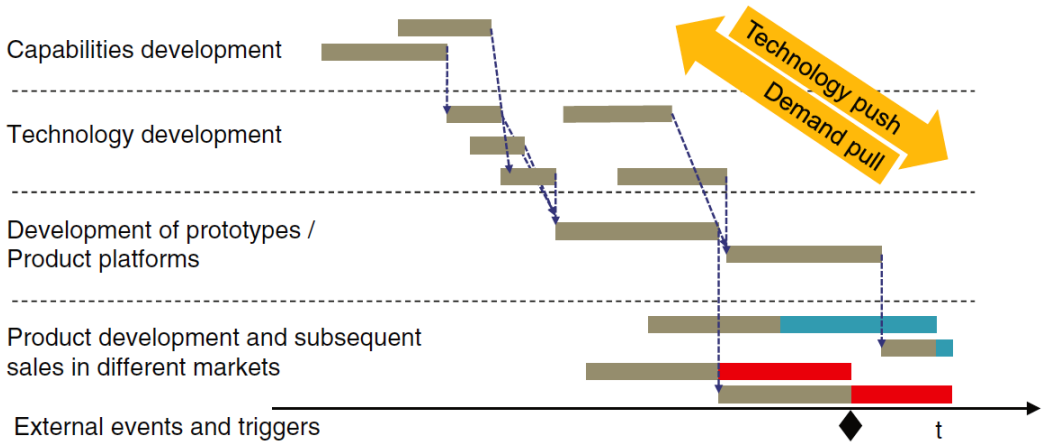


Figure 38. Example of technology roadmap, from (Cantamessa and Montagna, 2016)

There are some tools and methods associated to the TRM. Among others, incidence matrices, in which features at different upstream and downstream levels are mapped onto each other in order to translate market needs into technological priorities. The Customer Focused Technology Planning® (CFTP®) method, (Paap, 1994), proposes a 6-step roadmapping process which incorporates markets and customer segments as well as comparisons with competitors.

The technology roadmaps are widely used within industry for managing the future of technology on long-term horizons. Although there are some evidences of the successful application of TRM in SMEs (e.g., (Holmes and Ferrill, 2005; Jun et al., 2013; Battistella et al., 2015)) as well as some practical tools (such as T-Plan (Phaal et al., 2000) which supports its rapid start), TRM does not seem to be easily adaptable to the

context of technology-oriented innovative startups. Indeed, unlike larger firms that are guided by long-term planning, R&D activities in startups must be monitored by short range roadmaps.

The literature in entrepreneurship and in innovation management emphasizes that experimentation is the most important R&D activity of technology-oriented innovative startups (see for instance (Kerr et al., 2014; Blank, 2013; Ries, 2011)). In general, testing activities (or experiments) count for more than 50% of companies R&D expenditures (see for instance (Bertolino, 2007)), and more than 75% of their R&D time (see (Allen, 1966)). These percentages must be even higher in the context of an innovative technology startup, given their continuous experiments. Therefore, as the cost-effectiveness of experiment is challenging for these startups, it is worth focusing on how the testing activities are planned and roadmapped.

5.2.2. Planning and roadmapping of testing activities

The research works in the field of product development considers different aspects of testing, planning or scheduling during product development phases. Conventionally, testing in the front end of innovation consists in concept verification, competitive product analysis as well as project justifications. Besides, alternative concepts are generated as far as they are practicable to ensure the product's reliability, performance, and durability with respect to the customer needs (Lévárdy et al., 2004).

The front end of innovation requires special attention, as the fidelity and reliability of information available may be very limited while companies strive to reduce the time scale and the financial investment of the development cycle (Ayag, 2005; Ulrich and Eppinger, 2015). Therefore, testing at the front end of innovation plays a key role in identifying the aspects of the design with high risk and uncertainty as areas for future investigation.

To reduce uncertainties and risks before the launch of an innovation, product development can require many experiments. (Thomke, 2001) considers testing as a form of experimentation. He defines experimentation as a 4-step iterative process of creating knowledge which leads to the development and improvement of products, processes, systems, and organizations (Thomke, 2003). This process contains the following steps: Design (conceive new ideas and concepts); Build (build virtual or physical models); Run (run tests using built models); and Analyze (analyze observations and conclusions).

Beyond this general process of experimentation, two temporal experimentation strategies (sequential and parallel) can be highlighted for mitigating uncertainties across optimal planed tests (see for instance (Conti et al., 2013; Loch et al., 2001;

Thomke and Bell, 2001)). Weitzman (Weitzman, 1979) views testing as a sequential search for the best alternative among a set of discrete choices and derives, through a dynamic programming, a cost-optimal method. Based on Weitzman's approach, Loch et al. (Loch et al., 2001) developed an analytical model to determine an optimal balance of parallel and sequential testing. Their model considers optimal testing strategy as a function of testing cost, prior knowledge, and lead-time. Thomke and Bell (Thomke and Bell, 2001) revealed that a fundamental problem in managing product development is, optimal timing, frequency, and fidelity of sequential testing activities. They proposed a quantitative model that considers testing as an activity which generates information about technical and customer-need related problems.

In the literature of entrepreneurial innovation, little research has explored temporal strategies of experimentation in the context of startups. To our knowledge, only a recent publication (Davis et al., 2016) studies the entrepreneurial experimentation strategies. Using unique data from the iPhone application startups, authors found out that: (i) parallel experimental strategies are better suited to markets where there is need for matching potential innovation to a market need, and (ii) sequential strategies are better suited to markets where a certain level of quality is required to ensure purchases from customers. Although these results are original and insightful, the proposed models lack in providing practical experimentation roadmaps.

5.2.3. Summary of the identified lacks in the literature

The interdisciplinary literature in terms of monitoring R&D and testing activities shows that, in the context of technology-oriented innovative startups, the following needs are not necessarily satisfied:

- using and implementing practical tools to help startups roadmap their R&D investment;
- effectively allocating resources to the R&D and testing activities considering startup's limited time and resources;
- providing quantitative outcomes supporting a relevant decision making;
- scheduling experiments in short-term basis;
- modeling the nature of testing activities and their cost and time;
- ensuring the significance of users'/customers' problem (or needs) to be investigated from the front end of innovation.

To respond to the identified lacks, we propose a new methodology, called RITHM (standing for Roadmapping Investments in TecHnology and Markets), which is detailed and showcased in the following sections.

5.3. Introducing the RITHM methodology

The RITHM methodology aims at advising startups on both "*doing right things*" (rationally targeting markets) and "*doing things right*" (conducting optimal R&D activities). This methodology comprises a set of structuring principles and tools that make the R&D process of technology startups more efficient by identifying important unsolved or poorly defined problems of users.

A set of tools are provided by RITHM to better understand people's overlooked problems based on a *need seeker* approach (see (Jaruzelski et al., 2016)). This is in contrast with the classical R&D monitoring approaches that are either technology-push or demand-pull that are extensively focused on developing technological functions or are driven by the demand on the market.

The central hypothesis of the RITHM methodology is that it may be possible to increase startup's likelihood of success if its R&D process addresses one or several significant and useful problem(s). This entails that important R&D effort must concentrate on understanding and addressing users' jobs-to-be-done (Christensen, 2013) and problems instead of merely testing a solution prototype or developing an MVP (Minimum Viable Product).

To get an in-depth knowledge about users, RITHM has its origins in set-based thinking which consists in gathering, in advance, as much design information as possible in order to envision the consequences of a set of potential alternatives at any moment in the design process (see, e.g., (Yannou et al., 2013; Sobek et al., 1999)).

Compatible with the principles of set-based thinking, the Radical Innovation Design® (RID) methodology serves also as the basis of the RITHM methodology. RID is a process of systematic investigation in the front end of innovation along with a continuous uncertainty reduction that converges, before the solution and business design phases, towards a set of quantified *value buckets* (i.e., "*combinations of important problems/pains occurring during characteristic usage situations and for which existing solutions are generally neither useful nor efficient*" (Yannou, 2015)).

In the framework of the RITHM methodology, costly and time-consuming R&D activities are conducted once sufficient information is gathered regarding the end-users. Hence, the concurrent engineering process is optimized given that testing loopbacks are minimized thanks to the exploration in the front end of innovation. Ultimately, the RITHM methodology seeks to propose optimal R&D activities for markets where there is an important number of unsolved or poorly-solved problems.

The latter increases the likelihood of coming up with blue ocean innovations (Kim and Mauborgne, 2014) that can successfully penetrate profitable markets.

5.4. RITHM process

RITHM includes an organized process. Starting from a core technology, this process identifies and plan cost-efficient R&D activities. The RITHM process contains 10 steps (see Figure 39) and a set of tools for each step that are detailed in the following sections through a case study. These 10 steps are:

1. Investigation of technology's main usages;
2. For each identified usage, exploration of promising markets that have high value creation opportunities or important *value buckets* (i.e., frequent and important problems for which the existing solutions (e.g., competing technologies) are poorly or not at all efficient (Yannou et al., 2016));
3. Characterization of the properties or attributes of the core technology;
4. Evaluation of the market maturity gap that the technology must bridge (this gap is evaluated through a mechanism of dependency matrices);
5. Modeling R&D activities (hereinafter called "activities") that are typically broken down into basic research, applied research, and experimental development (see (OECD, 2015));
6. Quantification of the modified market maturity gap *after* activities (in other words, a new gap is estimated with activities);
7. Identification of possible activities for the company in terms of their financial cost and lead-time, and enabling the company to meet the most promising markets;
8. Identification of a set of alternatives with different trade-offs, called Pareto optimal solutions, or non-dominated solution;
9. Optimization of cost-effective sequences of individual activities to thoroughly plan and order activities by taking into account the constraints;
10. Optimization of sequences of combined activities called platforms of activities.

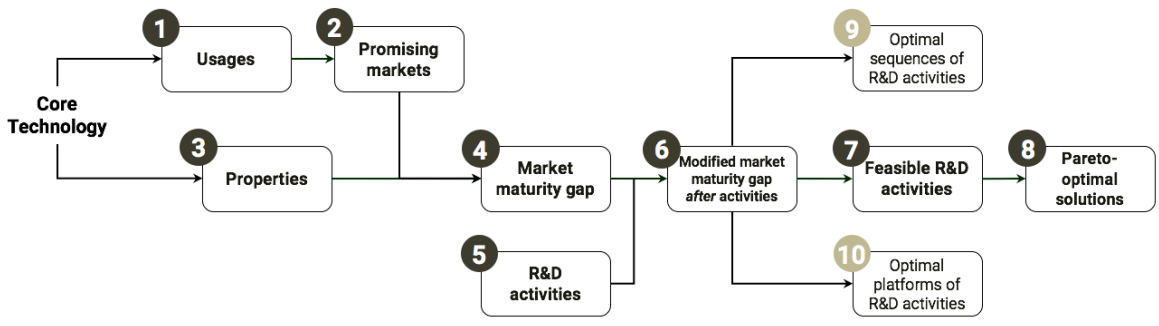


Figure 39. RITHM process

The first eight steps of this process are explained, in the following section, through a case study. The steps 9 and 10 are not detailed in this paper as they exceed the scope of this research.

5.5. Case study: a shape-changing technology

The RITHM methodology is deployed, during two months and following eight sessions of one to two hours, on a startup that has a patented innovative technology. This technology is a shape-changing plastic material that becomes flexible when plugged into a source of A/C current (see Figure 40).

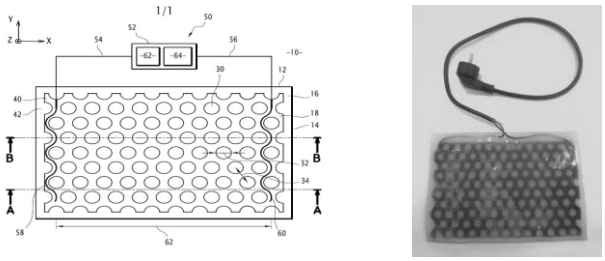


Figure 40. Schematic presentation of a section of the prototype (left) and the physical prototype (right)

The product is almost instantaneously deformable and reversible. Besides, when the electricity power is on the surface will get slightly warm. The technology can have various usages and can be exploited in different markets. The technology can be incorporated into daily objects and the user can adapt it to an expected shape. Some applications of this technology have already been identified by the startup. However, they are merely based on the intuition of entrepreneurs of the startup (see Figure 41 for examples where the technology can be introduced to improve the shape adaptation of objects such as shin guards, medical ventilation masks, and earphones). Startup's founders are aware of the Lean Startup method and have already adopted this approach with the development of an MVP and conducting loop-based tests. However, their main concern remains the maturation of their technology for the most promising markets.

Sports protections (e.g., shin guard) | *Medical ventilation masks (e.g., borders of ventilation masks)* | *Entertainment objects (e.g., earphones)*

Figure 41. Some of the identified applications by the startup developing the shape-changing technology

The **1st step** of the RITHM process consists in mapping different usages of the technology. This work is done by systematically exploring the situations where there is need to change and invert the shape of an object, regardless of the marketing and technical considerations. This exploration remains qualitative and through organized brainstorming sessions as follows: first, several lists of usages are created during the first session. Second, these lists are completed with further observations and investigations among different sources (e.g., patent bases, scientific publications, interviewing SMEs[16]). Third, the lists are combined to extract main the usage categories. The results of the three sessions of reflection are captured in heuristic maps.

In our case study, two main categories have emerged: (i) *human body interface* (i.e., the main usage is to adapt to the shape of the human body such as adapting to the shape of ears in earphones); (ii) *embedding and structuring objects* (i.e., the main usage is to make flexible a part of a physical tool/device without the need of adaptation to the human body). The detailed map of the first category is provided in 5.14.1. In this map, 66 different usages are identified, where only 20 have been already considered and partly studied by the startup and the rest have not yet been considered by the company.

In the **2nd step** the startup decided first to focus on the first category of usages as it contains more usages to be targeted (66 in the first category vs. 20 in the second). The 2nd step seeks to thoroughly explore each usage and to determine whether it is related to a promising market or not.

As mentioned previously, the focus of the RITHM methodology is on the usefulness of an innovative technology and its ability to address an important unsolved or poorly-solved problem of users. This falls within the definition of the Value Bucket (VB) as introduced in the RID methodology (Yannou et al., 2016; Lamé, Leroy, et al., 2017). Value Buckets are quantified by the DSM-Value Bucket algorithm which combines three dimensions (*problems*, *scenarios*, and *existing solutions*) in dependency matrices. These matrices (see Figure 42) compute the gap between matrix A (*problems* occurring in *scenarios*) and matrix D (overall effectiveness of the *existing solutions* to cope with these *problems*). Matrix D is per se obtained from the product

[16] Subject-matter experts

of intermediary matrices C and B (where matrix C reflects the effectiveness of the existing solutions in usage scenarios and matrix B represents the effectiveness of solutions to lower the problems). Finally, the algorithm computes the weighted value buckets in matrix E.

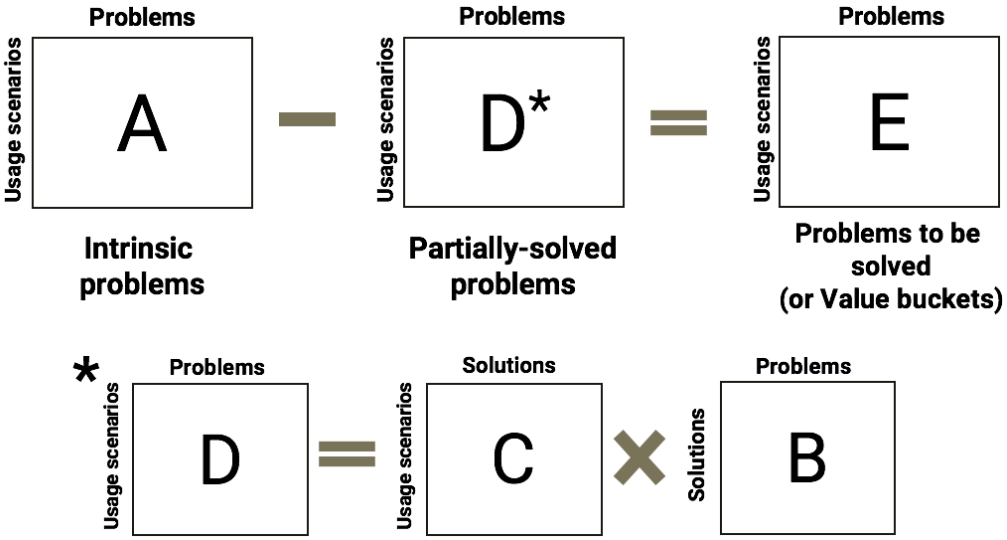


Figure 42. DSM value bucket algorithm

The identified value buckets contain relevant information on problems occurring in frequent justified scenarios that are worthy of being addressed by the technology. Each value bucket reflects therefore a promising market (i), and is characterized as combination of a *"problem"* in a *"usage scenario"*. This value buckets approach has proven to be relevant to elicit the innovation priorities. Some examples of its use are: in the context of dental imaging (Lamé, Yannou, et al., 2017), eco-designing buildings (Lamé, Leroy, et al., 2017), improving a wheelchair for hand tennis (Yannou et al., 2016), a smart lighting (Bekhradi et al., 2017).

For the sake of simplicity, we will consider in the rest of this paper only five markets from the 21 that are chosen by the startup in this step of the process:

- Cosmetic masks ("*poor oil distribution problem*" in "*home usages*")
- Shin guards ("*injury and bone fracture*" in "*tackle receiving*")
- Ski boots ("*injury and musculoskeletal disorders*" in "*long-term use*")
- Orthopedic insoles ("*time and efficacy loss*" in "*customizing orthopedic insoles*")
- Earphones ("*bad fitting in the ears*" in "*moving situations*").

Once the markets are identified, they are compared in terms of their attractiveness and potential of economic value creation. The question of assessing different markets is addressed in the abundant literature of marketing. For instance, (Armstrong et al.,

2014) discussed a set of techniques and indicators for market assessment, and (Best, 2012) proposed a quantification tool to assess the Market Attractiveness Index (MAI). Based on these works, we propose a quantification technique adapted to assess the MAI of an innovation technology with the help of six parameters (i.e., market size, market potential (or growth), ease of entry, likelihood of finding investors, customer acceptance, and distribution channel access). An intensity scale from 0 to 5 (with 5 as the most important or, for instance, the biggest or a very easily accessible market) is used to assess the value of each of the six parameters. The relative importance of each parameter is then weighted by using a zero to one intensity scale. All these values are determined by the startup based on their previous or ongoing market researches, and are validated by market experts.

The **3rd step** of the process involves a deep analysis of the technology through the identification of its main properties. A functional reasoning constitutes the basis of this analysis. As opposed to existing approaches that merely focus on the technical functions or technology affordances (see for instance (Gaver, 1991)), we emphasize the broader concept of usage situations and the possible usage coverage indicators of a technology as proposed and quantified by (Wang et al., 2013; Yannou et al., 2013). Therefore, an ontology (i.e., a generic technology characterization) is proposed to identify the key properties of the technology (see Figure 43). In this model, it is considered that a technology can be applied to different usages, where *important problems* occurring in *frequent usage situations* are to be covered by a set of expected usage coverage properties. These properties can be modeled through Usage Coverage Indicators (UCIs) that have been proposed to measure the potential to satisfy usage situations.

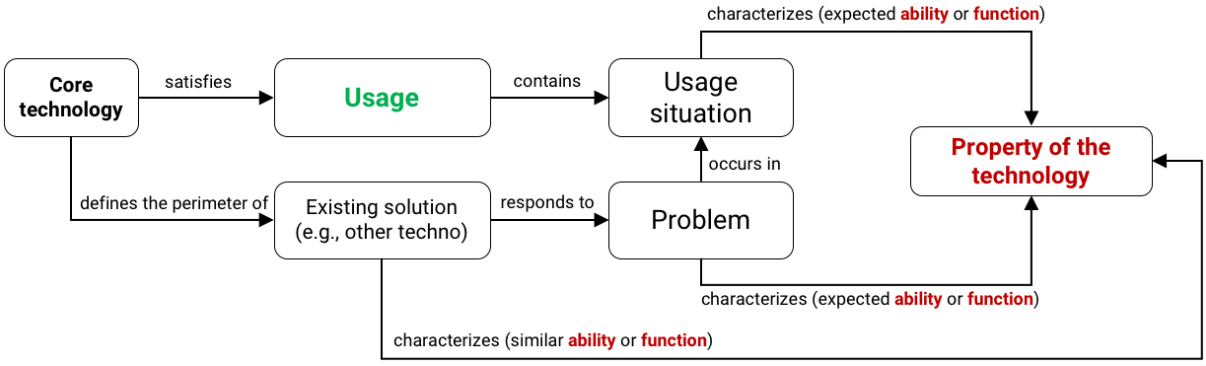


Figure 43. Ontology of the properties of a technology

This ontology is holistic in that it does not only specify technical attributes of existing solutions on the market, but it starts from a representative set of usages instead of being focused on (or fixed at) design parameters of a technological solution.

In our case study, 14 key properties of the technology are identified and defined (see 5.14.2). For the rest of this study, three properties are kept and analyzed. These properties are:

i. ability to cover bony parts of the human body
ii. heat setting
iii. compactness and portability (or practicality in terms of volume and size).

The maturity improvement of the identified properties involves multi-disciplinary investigations to gain knowledge and competencies about how the technological functions enable solving problems of users in different markets. For instance, the first property (the ability to cover bony parts of the human body) implies the principles of physics such as the curvature of the material. In the case of cosmetic masks, the radius of curvature of the surface must be thoroughly calculated to improve the oil distribution of the masks. Regarding the orthopedic insoles, the value of this radius is calculated differently to correct poor foot structure and deformities and thus reducing foot pains. This is therefore not only about gaining knowledge in physics of the material and of the human body, but also about understanding serious medical problems which are foot pains and deformities.

Indeed, this knowledge exploration work involves conducting several R&D activities that are not merely focused on prototype testing. The startup will be encouraged thus to acquire a new language and a superior knowledge, from the front end of innovation, about disciplines of interest and about the problems of users in different markets.

The next step of the process enables combining the properties of the technology with the identified markets in a set of dependency matrices (see 5.14.3 for an example of dependencies between the 21 identified markets and 14 main properties of the technology). These matrices will enable to compute the market maturity gap that the technology must bridge.

5.6. Quantification of the market maturity gap

At the **4th step** of the process, a DSM algorithm is proposed to cross the identified markets with the properties of the technology in two matrices (see Figure 44).

The first matrix (F) includes the required maturity for the technology (i.e., the threshold from which a technology is considered as “ready” to meet a given market). Here, the proposed intensity scale ranges from 0 to 5 (with 5 as the most mature property). The proposed scale differs from the conventional TRL (Technology Readiness Level). Indeed, the threshold level (α) is given per market and per property of the technology.

Its value indicates the degree to which a successful technology is already released on the market or can be approved for commercialization (e.g., as in the case with FDA-regulated medical technologies).

The second matrix (G) provides the values for the current maturity of the technology. The values of this matrix are declared by the startup and are validated by their innovation advisors. The difference between two matrices is given in matrices H and K (see Figure 44). The latter identify the market maturity gap that we call meta value buckets (mVB). The meta Value Buckets matrices can be considered as an extension to the Value Buckets matrices as detailed in previous section. Therefore, a new algorithm called DSM-meta Value Bucket (DSM-mVB) is forged here to compute the market maturity gap.

The data to complete DSM-mVB matrices are obtained through different complementary sources: (i) existing standards that a technology must comply with (a thorough review of the standards of each market is therefore mandatory); (ii) discussions with different SMEs who have an extensive knowledge about both markets and technologies; (iii) startup's knowledge and experience.

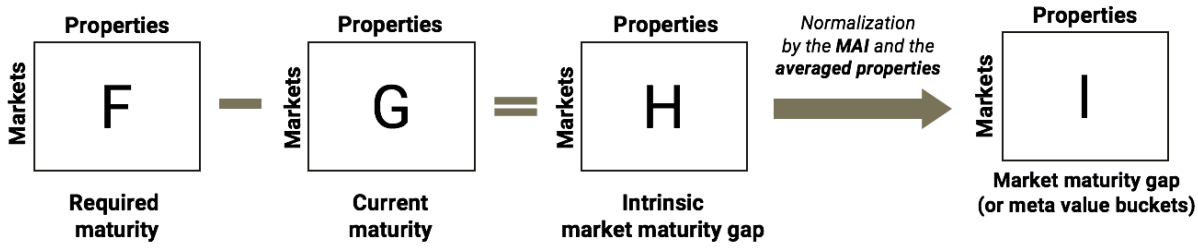


Figure 44. DSM meta value bucket algorithm

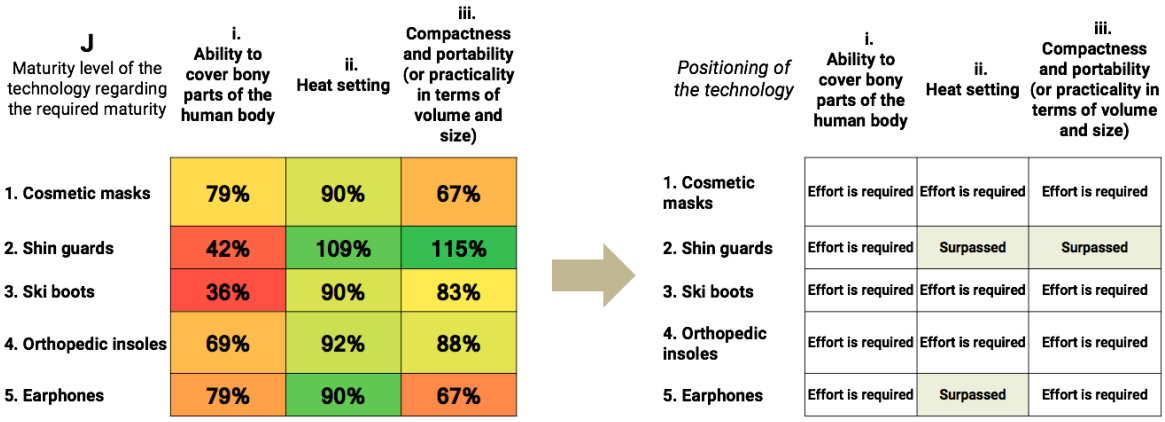
To capture the rationale of each market importance and the relative importance of the properties of the technology, the values in matrix H are normalized by referring to the averaged properties of the technology, obtained from matrix F, and to the Market Attractiveness Index (MAI). The last matrix (I) contains the normalized meta Value Buckets and its values (I_{ij}) are obtained by:

$$I_{ij} = H_{ij} \times MAI_i \times \overline{F_{ij}}, \qquad (1)$$

where i is the index representing a market and j the index related to a technology property.

Based on matrix I, a last matrix called "maturity level" (J) is computed to determine the percentage of the technology maturity. In matrix J (see Figure 45) if the value is equal to 100%, the current positioning shows "*Already reached*" maturity of the property of

the technology in this specific market, and indicates "*Surpassed*" if the value is higher than 100%.



J Maturity level of the technology regarding the required maturity	i. Ability to cover bony parts of the human body	ii. Heat setting	iii. Compactness and portability (or practicality in terms of volume and size)
1. Cosmetic masks	79%	90%	67%
2. Shin guards	42%	109%	115%
3. Ski boots	36%	90%	83%
4. Orthopedic insoles	69%	92%	88%
5. Earphones	79%	90%	67%

Positioning of the technology	i. Ability to cover bony parts of the human body	ii. Heat setting	iii. Compactness and portability (or practicality in terms of volume and size)
1. Cosmetic masks	Effort is required	Effort is required	Effort is required
2. Shin guards	Effort is required	Surpassed	Surpassed
3. Ski boots	Effort is required	Effort is required	Effort is required
4. Orthopedic insoles	Effort is required	Effort is required	Effort is required
5. Earphones	Effort is required	Surpassed	Effort is required

Figure 45. Matrix I and the interpretation of the current positioning of the technology regarding the identified gaps

A meta value bucket can be, for instance, expressed as: the ***ability to cover bony parts of the human body*** in the market of ***Ski boots*** (related to the value bucket: "*tiredness and musculoskeletal disorders" in "long-term use*).

5.7. Modeling R&D activities

The **5th step** of the process consists in modeling R&D activities and their impact in reducing the market maturity gap. These activities are modeled prior to their actual deployment by the startup as the objective is to predict and plan the optimal activities aiming at improving the technology to meet the most promising markets. Each activity must improve the current maturity of the technology and it is assumed to be distinct, i.e., a change in one activity does not affect the others.

The testing activities are at the core of the R&D activities of technology-based companies and mostly those of startups. An important part of their R&D investment is allocated to testing activities. Given the importance of the testing activities in the following, we will focus on testing activities in their broad sense, which includes four iterative steps of the experimentation process as formulated by (Thomke, 2003). These steps are: designing new concepts and models; building virtual and physical models; running tests using the built models; and analyzing observed phenomena. Obviously, each step takes time and it requires cash investments.

Based on this definition, we define a testing activity (or experiment) as: "*an action or procedure that has a financial cost and a lead-time, and which is carried out (once or*

iteratively) under controlled conditions to generate new knowledge leading to improve the maturity of a technology".

Based on this definition, the financial cost and the lead-time of a testing activity refer to the time investments made on the four above-mentioned steps of the experimentation process. The testing is carried out one or several times (an experimentation process is iterative) and it leads to the generation of new knowledge that must improve the maturity of the technology.

To model a testing activity in a standard manner, inspired by the works of (Cooper, 2011; Radder, 2003; Ballon et al., 2005) we propose a codification of EOSA testing attributes standing for *testing Environment, testing Operator, testing Strategy,* and *testing Artifact*. These attributes are not intended to be mutually exclusive. Each attribute contains a set of three to five modalities with a last modality "*Other*" that can be specified according to a given case (see Table 8).

Table 8. EOSA variables and modalities of a test

Attributes	Modality
Environment (E)	*E1: Real-life situation* *E2: Traditional lab (simulated situation)* *E3: Web-based lab* *E4: Other*
Operator (O) or user	*O1: Real end-users* *O2: Simulating Users* *O3: Engineers* *O4: Other*
Strategy of conducting testing activities (S)	*S1: Blind or double-blind tests* *S2: Test and control group* *S3: Parallel test* *S4: Sequential test* *S5: Other*
Testing Artifact (A)	*A1: Physical prototype* *A2: Software modules* *A3: Other*

In our case study, the startup has expressed 15 testing activities based on the combinations of these EOSA modalities. In the rest of this paper, only five testing activities are maintained for the sake of simplification:

- Building physical prototypes to be tested in the lab (such as alpha tests): [A_1; E_2]

- Numerical simulations on the ratio of shape-changing to the size and type of materials: [A_2; S_3]
- Blind testing the prototype with real users in real-life situations: [S_1; O_1; A_1; E_1]
- Testing the physical prototype with real users in real-life situations following a test and control technique [A_1; O_1; E_1; S_2]
- Randomized field trials of the physical prototype in simulated situations [S_3; A_1; E_2].

Once the testing activities are characterized, three key variables are measured per each activity: expected improvement rate (e_{IR}) in percentage; the financial cost (C) in euros (as the sum of the cost of each of the four conventional steps of the experimentation process); and the lead-time (T) in months (from the initiation to completion of the experimentation process). The value of these variables is declared by the startup according to their previous testing activities and validated through a data collection and validation process explained later in this paper.

According to the proposed definition a testing activity, the procedure of testing can be conducted "in one go" or iteratively. Therefore, the data declared for the three above-mentioned variables must consider how many time the procedure of testing is repeated.

5.8. Quantification of the modified market maturity gap

The **6th step** of the process quantifies the modified market maturity gap *after* testing activities. It is assumed that a testing activity cannot deteriorate the maturity of a technology. In other words, the value of e_{IR} variable is greater or equal to zero. Therefore, it reflects maturity improvement in the properties of the technology in the identified markets. Therefore, the modified market maturity gap g_M is given by

$$g_M(a,i) = \alpha - h\big(e_{IR}(a,i)\big), \qquad (2)$$

where α is the threshold maturity and $h\big(e_{IR}(a,i)\big)$ is the function that calculates the improved maturity of the technology *after* testing activity a for market i for all of the identified properties of the technology.

The objective of testing activities is to reduce the market maturity gap in order to ultimately penetrate this market. However, the question is: considering a set of testing activities for different markets, which activity should be chosen? To answer this question, two alternative objective functions can be considered.

The first objective function rewards testing activities that improve maturity as much as possible. In other words, it will seek the smallest value of market maturity gap. In case more than one testing activities allow penetrating a market, the activity which exceeds the threshold the most will be chosen:

$$\min_{a,\,i} \; g_M(a,i). \tag{3}$$

The second objective function does not reward the maximization of market maturity. Once a testing activity enables reaching the threshold for a market, it is not considered better or worse than any other activity that has also enabled reaching a market:

$$\min_{a,\,i} \; \max(\alpha, g_M(a,i)). \tag{4}$$

In our study, we will focus on the first alternative as the data declared by the startup are estimations, and it is more cautious to reward the activities that maximize maturity. It must be noted that “exceeding the maturity level” and “penetrating a market” do not necessarily mean that the technology will be commercialized and can be effectively launched on the market after conducting the testing activity. It merely means that the technology reaches a high likelihood of successfully penetrating the market, as it is mature enough and it targets the relevant value buckets (or value creation opportunities).

The total financial cost and lead-time of a testing activity may depend on several variables such as: the investment needed to design an activity, the number of physical and/or virtual model built to be tested, and the number of actors involved in testing. However, these independent variables are not generic and vary from context to context. Therefore, to provide a general framework without detailing the specific independent variables, we consider a simple model of cost and time breakdown structure. In this model, the total cost and lead-time are considered as the sum of the distinctive costs and time of each of the four steps of the experimentation process. The values of cost $C(a,i)$ and time $T(a,i)$ are declared by the startup per testing activity a and market i.

The purpose of the RITHM process is to identify optimal activities that simultaneously reduce cost, time, and market maturity gap. The following section focuses on the identification of cost-effective experiments.

5.9. Optimization of testing activities

The **7th and 8th steps** of the process consist in identifying optimal testing activities. These steps aim at identifying, for a given market, a testing activity that allows reducing the distance between the required and improved maturities of the technology without being costly and time-consuming. In this context, a multi-objective optimization problem is formulated to minimize these possibly conflicting objectives:

$$\min_{a,i} \begin{bmatrix} g_M(a,i) \\ C(a,i) \\ T(a,i) \end{bmatrix} \quad (5)$$

subject to the following constraints:

$$\begin{aligned} g_1(a,i) &\leq 0 \\ g_2(a,i) &\leq B \\ g_3(a,i) &\leq T_A \end{aligned} \quad (6)$$

The first constraint implies that the model must maintain those activities that enable exceeding the maturity threshold. In other words, the market maturity gap is less than or equal to zero. The second and third constraints ensure that the cost and lead-time of a testing activity do not exceed the available budget of the startup B and the available time of the startup based on an already-fixed deadline to launch a product or to respond to a call for project or tender for instance T_A, respectively.

The solution of this multi-objective problem is a set of Pareto-optimal points. In our case study, we consider five identified markets and five testing activities. Figure 46 depicts market maturity gap, cost and time for all 25 possible combinations.

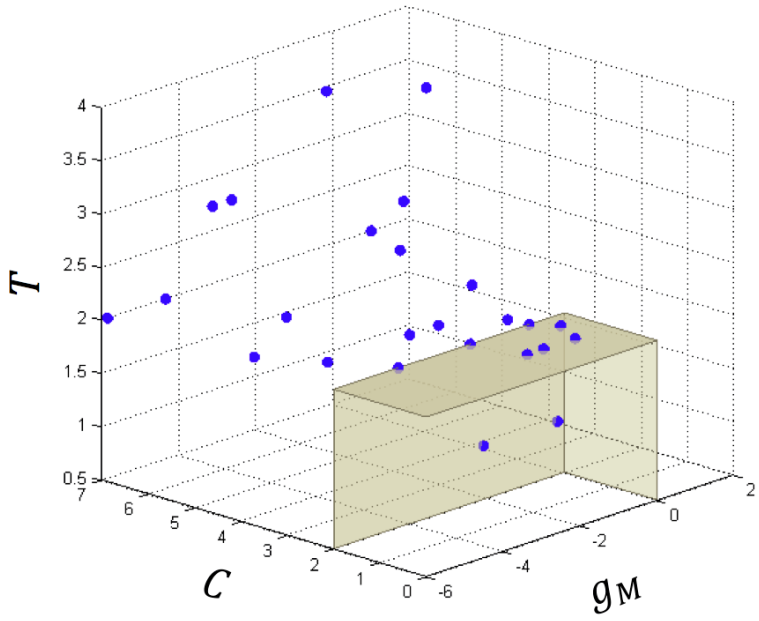


Figure 46. Market maturity gap, cost, and time for all possible testing activities and markets

The budget is €10,000 and the available time is set as 1 month. The maturity threshold is 0. Thus, we can plot the boundaries of the three constraints and determine that only 9 of the points are feasible with respect to the three constraints.

The identification of non-dominated points is performed using Kung's method (Kung et al., 1975): we first sort the population in descending order of importance of the first objective function. Then, the population is recursively halved as top and bottom sub-populations. As top half is better in objective in comparison to bottom half in first objective, we thus verify the bottom half for domination with top half. The solution of bottom which are not dominated by solutions of top are merged with members of top to form merged population. By deploying Kung's method, three Pareto-optimal points among the 9 feasible points are identified: 1, 3, and 4 (see Table 9).

Table 9. Feasible and Pareto-optimal points

Solution number	Solution vector	g_M	C	T
(1)	$\begin{bmatrix} \boldsymbol{A} \\ \mathbf{1} \end{bmatrix}$	**-4.32**	**2.00**	**2.00**
(2)	$\begin{bmatrix} A \\ 2 \end{bmatrix}$	-2.45	2.00	2.00
(3)	$\begin{bmatrix} \boldsymbol{A} \\ \mathbf{4} \end{bmatrix}$	**-2.18**	**1.00**	**2.00**
(4)	$\begin{bmatrix} \boldsymbol{B} \\ \mathbf{2} \end{bmatrix}$	**-2.11**	**2.00**	**1.00**

(5)	$\begin{bmatrix} C \\ 2 \end{bmatrix}$	-1.75	1.00	2.00
(6)	$\begin{bmatrix} C \\ 5 \end{bmatrix}$	-0.93	1.00	2.00
(7)	$\begin{bmatrix} D \\ 4 \end{bmatrix}$	-0.93	2.00	2.00
(8)	$\begin{bmatrix} E \\ 2 \end{bmatrix}$	-0.59	1.60	2.00
(9)	$\begin{bmatrix} E \\ 5 \end{bmatrix}$	-0.18	2.00	1.00

We call the three non-dominated solutions **Minimum Viable Experiments (MVEs)** as they increase the likelihood of successfully penetrating the most profitable markets with minimum investments in time and cash. An MVE must therefore enable reaching a beach-head market (i.e., the easiest market to capture which is big enough to generate needed cash flow to gain more markets). The Pareto-optimal solutions provide a rational choice of these beach-head markets that are: the cosmetic masks, shin guards, and orthopedic insoles markets.

The effectiveness of conducting the first and second testing activities (i.e., building physical prototypes and specific numerical simulations) on these three markets is also justified. According to the possible trade-offs between the three optimization objectives (see Table 10), the startup must take a strategic stance. The latter will depend not only on the startup's business culture, but also on the willingness of its staff to focus on a given market and testing activity. A fast-growing startup already operating in an emerging field might pursue a visionary strategy by, for instance, focusing on markets with important entry barriers, while a new established startup might find it rational to follow a more cautious strategy.

Table 10. Trade-offs between the three objectives of the RITHM multi-objective optimization

MVE	Market maturity gap (%)	Cost (€)	Lead-time (month)
$\begin{bmatrix} A \\ 1 \end{bmatrix}$	-20%	10,000	1
$\begin{bmatrix} A \\ 4 \end{bmatrix}$	-10%	5,000	1
$\begin{bmatrix} B \\ 2 \end{bmatrix}$	-10%	10,000	0.5

These results provide first-cut elements to build a strategic roadmap which enables a startup to organize and structure its R&D activities. However, in most situations startups conduct several activities and focus on several markets in parallel. Therefore, a more detailed map of activities needs to be outlined based on the sequences of

individual activities and also the sequences of combined activities that we may call **Minimum Viable Experiment Platforms (MVEPs)**. The optimization of such roadmaps exceeds the scope of this paper as they require a more complex modeling and a thorough extensive data collection and validation.

5.10. Data collection and validation of results

In general, raw data exist only about the past. The RITHM process is also fed with retrospective information to predict what will happen in terms of future testing activities, or to confirm what have already happened in the past. However, in this context there exist multiple challenges such as collecting the right datasets through surveys or observational study, generating new data (if necessary) through rapid experiments, categorizing or re-organizing data, and also extrapolating from the existing data. In order to face these challenges, RITHM proposes a systematic data collection and verification protocol to ensure the reliability and the accuracy of the data.

The data collection and validation procedure includes the following steps: (i) mapping data sources and relevant stakeholders, (ii) implementing investigation strategies (survey, new experiments, simulations, interviews with identified stakeholders (e.g., experts in technology and market, customers and end-users), (iii) monitoring the input data and cross-checking its significance through expert validation, and (iv) verifying the significance of the results.

The first and second steps of this procedure consists of identifying different data sources to collect data from such as review of the existing documents on potential usages and technologies, company previous tests and obtained results, agile-rapid iterative micro-tests to capture data for future tests, observations of usage situations, interviews with users and test operators in other companies, and a set of heuristics based on entrepreneurs' intuition and common sense following structured brainstorming sessions.

All the above-mentioned elements are confirmed, at the third step of the procedure, by innovation and SMEs (subject-matter experts) that are mainly startups' advisors and mentors with a solid knowledge of different markets and technologies. Even though it can be argued that experts can sometimes be subjective, it should be noted that each expert is questioned in accordance with their specialization and field-related knowledge. Moreover, the precision of the collected quantified data (mainly for establishing the 0 to 5 intensity scales) is not an issue in the RITHM process, since the relative importance of the matrices and meta value buckets matters more than their intrinsic values.

Finally, several means of one or several of the following will serve to perform post-optimality analysis to check the appropriateness of the results:

- If available, comparison with historical data on experiments already conducted by the startup or by a similar company with similar technology and conditions;
- Both sets of recommended and not-recommended testing activities are carried out by the startup to assess retrospectively the significance of the results;
- Experts' confirmation based on their previous knowledge of similar cases;
- Startup's general appreciation and intuition: if the final results reaffirm the testing activities and markets that have been actively targeted by the company.

5.11. Discussions

5.11.1. Relevance of the results for the entrepreneurial ecosystem

First, RITHM produces a primary set of quantified results in terms of purposeful technology maturation. Compared to broadly adopted methods in entrepreneurship, the RITHM methodology does not merely rely on generic guidelines and concepts but introduces quantitative tangible results that help make relevant investment decisions.

Second, RITHM provides structured information that helps a startup endorse its alignment of resources and strategic visions. The studied startup in this paper asserted that its staff operates henceforth with action plans, and work towards common goals.

Third, the studied startup leveraged the RITHM optimization results to further reinforce its fund-raising arguments by setting priorities, and justifying the purpose of the funds to be raised.

Fourth, innovation advisors may also benefit from the tools of the RITHM methodology to better advise startups on R&D planning. RITHM can therefore be considered as a tool for effective consulting that enables better steering a startup's investments.

5.11.2. Implications for academic and industrial stakeholders

The attitude of investigating from the front end of innovation highlights the necessity for a more forward-thinking culture or a teleological process as opposed to a teleonomic one (see, e.g., the effectuation theory (Sarasvathy, 2001)). Moroz and Hindle underline that one of the important limitations of the such a theory is the dearth of planning as a "*necessary and sufficient component of any purposive entrepreneurial process*" and not as in a formally articulated business plan (Moroz and Hindle, 2012).

Empirical surveys and analysis of high-tech small and medium businesses reaffirm that setting strategic plans matters even more to technology startups (Battistella et al., 2015; Berry, 1998; Stonehouse and Pemberton, 2002). Following this line of argument, the RITHM methodology nurtures such plans and introduces experimentation roadmapping as a new dimension to the strategic planning for entrepreneurial firms.

5.11.3. Areas of improvement

The current version of the RITHM methodology does not support the sequential and parallel testing activities. However, startups conduct several experiments on several markets in parallel. Hence, the optimization results presented in this paper are limited in predicting the upcoming activities and in specifying detailed roadmaps. There is therefore need to develop other optimization models to tackle this issue.

The quantitative estimation of the *expected improvement rate* variable is not an easy task, as the experiments are not yet conducted and data are not available on their improvement rate. The data regarding the cost and lead-time are also unavailable. Therefore, estimations may remain rough guesses. Aware of this limitation, in future versions of RITHM we will work on improving the ways of estimating such data.

Another important assumption is that the iterations of a testing activity are inherent to this activity, i.e., the number of iterations, their cost, time, and impact on the maturity are already included in the characteristics of this activity. The concept of iteration as well as the parameterization of testing activities represent an important area of improvement of the current version of RITHM.

Regarding the technology characterization, it has been assumed that improving the maturity of a given property of the technology does not affect the maturity of other properties. This is of course not true. For instance, reducing the size of a shape-changing product (to make it more easily portable) decreases its adaptation property. These interdependencies are not yet modeled in the RITHM methodology, since we first focus on the global consistency of experiments by assuming that all of the properties of the technology must be improved through testing regardless of their dependencies.

Finally, the market and competing technologies are subject to fast and constant evolutions. We are aware of this ever-changing environment for startups. Therefore, the next versions will intend to include a dynamic modeling of startup’s experiments.

5.12. Conclusion and future work

The issue of planning R&D activities in technology-oriented innovative startups is not sufficiently addressed by the existing literature. To tackle this issue, this paper aimed at proposing a model-based innovation approach called RITHM. The objective of RITHM is to steer startup's investments to those R&D activities that are worthy of being conducted, as they enable to mature the technology to meet the most promising markets.

The RITHM methodology comprises a step-by-step process, a set of tools, quantitative indicators, and optimization models. The RITHM process incorporates the linkage between promising markets and the properties of the technology in a set of matrices that compute the market maturity gap. Then, R&D activities as well as their cost, lead-time, and impact on reducing the identified gap are modeled. Further, an optimization model is proposed to find Pareto-optimal activities.

The RITHM methodology has been applied to the case of testing activities of a startup that has patented a shape-changing technology. The application of RITHM was that the results were satisfactory to build first systematic roadmaps that are of keen interest to entrepreneurial ecosystem. The studied startup has used the optimization results to justify and consolidate its fundraising arguments. Besides, the results obtained from the application of RITHM contributed to a better organization of the startup's workload. It is therefore possible to conclude that more organized and rigorous R&D activities do not harm startup's lean mindset.

Our future researches will have multiple objectives. First, conducting more case studies to robustify RITHM models and tools. For instance, the RITHM process can be applied to itself in order to plan future tests and maturation of a hands-on software application called *Alpha-RITHM*. Second, another perspective that we may be reasonably confident to focus on is to assess more accurate investment roadmaps based on the expectancy from the return on investment (ROI) on a product launched on the market. A parallel might be made with the real option valuation technique (see, e.g., (Copeland and Copeland, 2003)) to fine-tune decision-making aid of RITHM. Finally, a particular focus should be brought on the optimization of sequences and platforms of R&D activities by means of mixed variable programming (Kokkolaras et al., 2001) to fit RITHM models to data with specific techniques such as curve fitting and surrogate assisted optimization (Talgorn et al., 2015).

Acknowledgments

The authors wish to warmly thank the startup studied in this paper. The support of the first author through MITACS Globalink grant IT08957 is greatly appreciated.

5.13. References

Allen, T. J. (1966). Studies of the problem-solving process in engineering design. *IEEE Transactions on Engineering Management*(2), 72-83.

Armstrong, G., Adam, S., Denize, S., and Kotler, P. (2014). *Principles of marketing* (6th edition ed.): Pearson Australia. 1486002536.

Astebro, T. (2004). Key success factors for technological entrepreneurs' R&D projects. *IEEE Transactions on Engineering Management, 51*(3), 314-321.

Ayag, Z. (2005). An integrated approach to evaluating conceptual design alternatives in a new product development environment. *International Journal of Production Research, 43*(4), 687-713.

Ballon, P., Pierson, J., and Delaere, S. (2005). *Test and experimentation platforms for broadband innovation: Examining European practice*. Paper presented at the Conference Proceedings of 16th European Regional Conference by the International Telecommunications Society (ITS), Porto, Portugal. 4-6 September 2005.

Battistella, C., De Toni, A. F., and Pillon, R. (2015). The Extended Map methodology: Technology roadmapping for SMES clusters. *Journal of engineering and technology management, 38*, 1-23.

Bekhradi, A., Yannou, B., and Cluzel, F. (2018). Do innovative startups rigorously design and test a product or service? *Submitted to Journal of Small Business Management*.

Bekhradi, A., Yannou, B., Cluzel, F., Chabbert, F., and Farel, R. (2015). *In Vivo In Situ Experimentation Projects by Innovative Cleantech Start-Ups in Paris*. Paper presented at the ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. http://dx.doi.org/10.1115/DETC2015-47631

Bekhradi, A., Yannou, B., Cluzel, F., and Vallette, T. (2017). *Categorizing user pains, usage situations and existing solutions in front end of innovation: The case of smart lighting project*. Paper presented at the The 21st International Conference on Engineering Design, ICED17, Vancouver, British Columbia, Canada. August 21-25.

Berry, M. (1998). Strategic planning in small high tech companies. *Long range planning, 31*(3), 455-466.

Bertolino, A. (2007). *Software testing research: Achievements, challenges, dreams*. Paper presented at the 2007 Future of Software Engineering.

Best, R. (2012). *Market-based management*: Pearson Higher Ed. 9780133071627.

Blank, S. (2013). *The four steps to the epiphany: successful strategies for products that win*. New Jersey, United States: BookBaby. 0989200523.

Cantamessa, M., and Montagna, F. (2016). *Management of innovation and product development*. London, United Kingdom: Springer. 1447167228.

Christensen, C. (2013). *The innovator's dilemma: when new technologies cause great firms to fail*. Massachusetts, United States: Harvard Business Review Press. 9781633691780.

Conti, R., Gambardella, A., and Novelli, E. (2013). Research on markets for inventions and implications for R&D allocation strategies. *Academy of management Annals, 7*(1), 717-774.

Cooper, R. G. (2011). *Winning at new products: Creating value through innovation*: Basic Books (AZ). 0465025781.

Copeland, T., and Copeland, T. E. (2003). *Real Options, Revised Edition: A Practitioner's Guide*: Texere Publishing Ltd. 1587991861.

Davis, J., Chhabra, Y., and Yin, P.-L. (2016). *Experimentation Strategies and Entrepreneurial Innovation: Parallel and Sequential Innovation in the iPhone App Ecosystem*. Retrieved from

Deeds, D. L. (2001). The role of R&D intensity, technical development and absorptive capacity in creating entrepreneurial wealth in high technology start-ups. *Journal of engineering and technology management, 18*(1), 29-47.

Gaver, W. W. (1991). *Technology affordances.* Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

Holmes, C., and Ferrill, M. (2005). The application of operation and technology roadmapping to aid Singaporean SMEs identify and select emerging technologies. *Technological Forecasting and Social Change, 72*(3), 349-357.

Jaruzelski, B., Staak, V., and Shinozak, A. (2016, Winter 2016). Global Innovation 1000 : Software-as-a-Catalyst, The world’s largest innovators are shifting the focus of their R&D investments from products to programming. *strategy+business*.

Joglekar, N. R., and Levesque, M. (2009). Marketing, R&D, and startup valuation. *IEEE Transactions on Engineering Management, 56*(2), 229.

Jun, S.-P., Seo, J. H., and Son, J.-K. (2013). A study of the SME Technology Roadmapping Program to strengthen the R&D planning capability of Korean SMEs. *Technological Forecasting and Social Change, 80*(5), 1002-1014.

Kass, R. A. (2008). Tests and Experiments: Similarities and Differences. *International Test and Evaluation Association, 29*, 294–300.

Kerr, W. R., Nanda, R., and Rhodes-Kropf, M. (2014). Entrepreneurship as experimentation. *Journal of Economic Perspectives, 28*(3), 25-48.

Kim, W. C., and Mauborgne, R. A. (2014). *Blue ocean strategy: how to create uncontested market space and make the competition irrelevant*. Massachusetts, United States. 1625274505.

Kokkolaras, M., Audet, C., and Dennis, J. E. (2001). Mixed variable optimization of the number and composition of heat intercepts in a thermal insulation system. *Optimization and Engineering, 2*(1), 5-29.

Kung, H.-T., Luccio, F., and Preparata, F. P. (1975). On finding the maxima of a set of vectors. *Journal of the ACM (JACM), 22*(4), 469-476.

Lamé, G., Leroy, Y., and Yannou, B. (2017). Ecodesign tools in the construction sector: Analyzing usage inadequacies with designers' needs. *Journal of cleaner production, 148*, 60-72.

Lamé, G., Yannou, B., and Cluzel, F. (2017). Usage-driven problem design for radical innovation in healthcare. *BMJ Innovations, 4*(1), 15-23.

Lévárdy, V., Hoppe, M., and Browning, T. R. (2004). *Adaptive test process: an integrated modeling approach for test and design activities in the product development process.* Paper presented at the ASME 2004 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Loch, C. H., Terwiesch, C., and Thomke, S. (2001). Parallel and sequential testing of design alternatives. *Management Science, 47*(5), 663-678.

Moogk, D. R. (2012). Minimum viable product and the importance of experimentation in technology startups. *Technology Innovation Management Review, 2*(3).

Moroz, P. W., and Hindle, K. (2012). Entrepreneurship as a process: Toward harmonizing multiple perspectives. *Entrepreneurship Theory and Practice, 36*(4), 781-818.

OECD. (2015). *Frascati manual 2015: guidelines for collecting and reporting data on research and experimental development*: OECD Publishing. 9264238808.

Paap, J. E. (1994). Technology management and competitive intelligence: new techniques for a changing world. *Competitive Intelligence Review, 5*(1), 2-4.

Phaal, R., Farrukh, C., and Probert, D. (2000). *Fast-start technology roadmapping.* Paper presented at the Proceedings of the 9th International Conference on Management of Technology (IAMOT 2000).

Phaal, R., Farrukh, C. J., and Probert, D. R. (2004). Technology roadmapping—a planning framework for evolution and revolution. *Technological Forecasting and Social Change, 71*(1-2), 5-26.

Radder, H. (2003). *The philosophy of scientific experimentation*: University of Pittsburgh Pre. 0822972395.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

Sarasvathy, S. D. (2001). Causation and effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency. *Academy of management Review, 26*(2), 243-263.

Shane, S. A., and Ulrich, K. T. (2004). 50th anniversary article: Technological innovation, product development, and entrepreneurship in management science. *Management Science, 50*(2), 133-144.

Sobek, D. K., Ward, A. C., and Liker, J. K. (1999). Toyota's principles of set-based concurrent engineering. *Sloan management review, 40*(2), 67.

Stonehouse, G., and Pemberton, J. (2002). Strategic planning in SMEs–some empirical findings. *Management decision, 40*(9), 853-861.

Talgorn, B., Le Digabel, S., and Kokkolaras, M. (2015). Statistical surrogate formulations for simulation-based design optimization. *Journal of Mechanical Design, 137*(2), 021405.

Thomke, S. (2001). Enlightened experimentation: The new imperative for innovation. *Harvard business review, 79*(2), 66-75.

Thomke, S., and Bell, D. E. (2001). Sequential testing in product development. *Management Science, 47*(2), 308-323.

Thomke, S. H. (2003). *Experimentation matters: unlocking the potential of new technologies for innovation*: Harvard Business Press. 1578517508.

Ulrich, K., and Eppinger, S. (2015). *Product design and development*: McGraw-Hill Higher Education. 1259297136.

Wang, J., Yannou, B., Alizon, F., and Yvars, P.-A. (2013). A usage coverage-based approach for assessing product family design. *Engineering With Computers, 29*(4), 449-465.

Weitzman, M. L. (1979). Optimal search for the best alternative. *Econometrica: Journal of the Econometric Society*, 641-654.

Wu, J. J., and Atkinson, R. (2017, November 2017). How Technology-Based Start-Ups Support US Economic Growth. Retrieved from: https:// http://www2.itif.org/2017-technology-based-start-ups.pdf. Access date: July 2018.

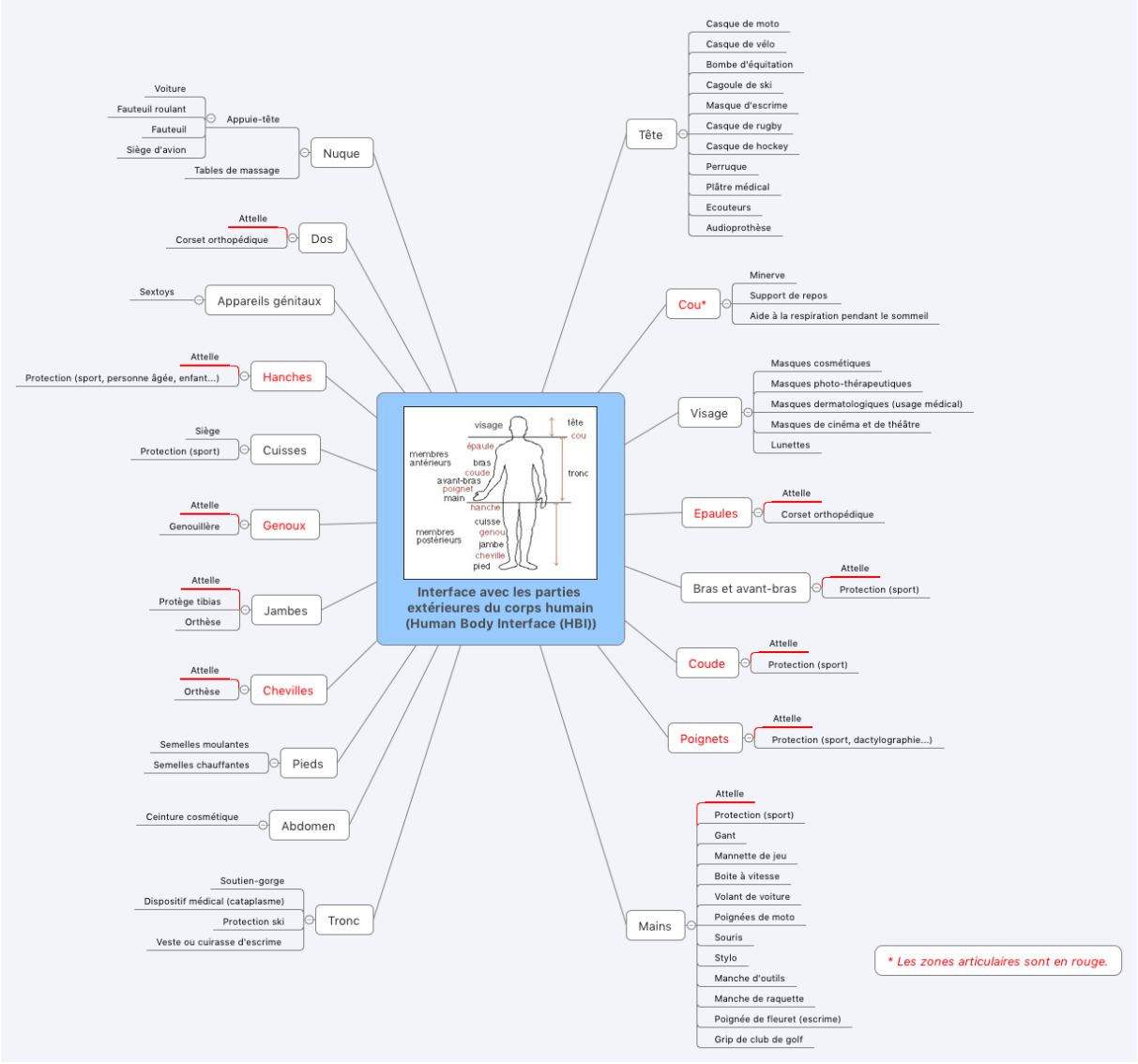
Yannou, B. (2015). *Supporting need seeker innovation: the Radical Innovation Design methodology*. Paper presented at the International Conference on Engineering Design (ICED).

Yannou, B., Cluzel, F., and Farel, R. (2016). Capturing the relevant problems leading to pain and usage driven innovations: the DSM Value Bucket algorithm. *Concurrent Engineering: Research and Applications*, 1 - 16. doi:10.1177/1063293x16666311

Yannou, B., Yvars, P.-A., Hoyle, C., and Chen, W. (2013). Set-based design by simulation of usage scenario coverage. *Journal of Engineering Design, 24*(8), 575-603.

5.14. Appendices

5.14.1. Appendix 1. Human body interface (HBI) category of usages of the shape-changing technology



5.14.2. Appendix 2. Identified properties of the shape-changing technology

No.	Properties of the technology	Definition
1	**Ability to cover bony parts of the human body**	Covering surfaces with direct contact with bones (e.g., cheek, back of head, forehead, hip, leg…) through a rigid contact surface in order to protect the body from external shocks or dangerous movements.
2	**Ability to cover non-pliable parts of the human body**	Covering non-articular parts of the human body (e.g., face, abdomen, dorsum…) in order to adapt their morphology.
3	**Ability to cover pliable parts of the human body**	Covering articular parts of the human body (elbow, wrist, shoulder…) in order to take the form of its pliable parts.
4	**Ability to immobilize parts of the human body**	Immobilizing pliable or non-pliable parts of the human body after a fracture or accident to avoid medical disorders or, to fix a part of the human body for specific medical interventions (e.g., surgery, radiology…).
5	**Ability to vary the thickness of the deformable surface**	Variability in terms of thickness of the surface to be adaptable to desired usage situations (without harming other abilities) (e.g., some parts of the covered surface need to be protected with a thicker deformable surface).
6	**Acceptability for a long-term contact with the skin**	Quality of the used materials that must not cause allergies or cutaneous problems.
7	**Adaptation to complex and polygonal surfaces**	Adapting to the form of a surface with complex and/or variable geometry (e.g., on the surface of the human body or objects in contact with the body), i.e., being polymorphic in order to cover polygonal surfaces and being ergonomic.
8	**Capacity of shifting from a shape to another**	Shifting from different shapes to others from the initial state (i.e., reversibility) to be able to build multiple forms from a current state.
9	**Hardness of the deformable surface**	Degree of rigidity of the deformable surface to resist to shocks or to immobilize in a satisfying way.
10	**Homogenous deformation on the deformable surface**	Degree of homogeneity on the whole surface to guarantee a coherent coverage.
11	**Possibility of the heat setting (thermal comfort)**	Possibility to control the heat degree and its duration to obtain an ideal thermal comfort.
12	**Practicality in terms of volume and portability**	Degree of importance of considering product's weight in different usage situations mainly if carried on the body.
13	**Reliability of materials for multiple shape shifting**	Degree of robustness of the used materials in order to resist multiple shape shifting in different usage situations depending on the number of deformations/formations and desired geometries before becoming obsolete.
14	**Speed of shape shifting**	Time needed to switch between different forms until becoming rigid enough.

5.14.3. Appendix 3. Matrix of required maturity with the 21 identified markets and 14 properties of the shape-changing technology

	F Required maturity	Ability to cover bony parts of the human body	Ability to cover non-pliable parts of the human body	Ability to cover pliable parts of the human body	Ability to immobilize parts of the human body	Ability to vary the thickness of the deformable surface	Acceptability for a long term contact with the skin	Adaptation to complex and polygonal surfaces	Capacity of shifting radically from a shape to another	Hardness of the deformable surface	Homogenous deformation on the deformable surface	Possibility of the heat setting (thermal comfort)	Practicality in terms of volume and portability	Reliability of the materials for multiple shape shifting	Speed of shape shifting
NIV Masks1	[Child patient x Air leakage]	5	5	0	0	2	5	3	3	0	4	2	4	3	4
NIV Masks2	[Elderly patient x Physical pain (sore, skin irritation...)]	5	5	0	0	2	5	4	3	0	4	2	4	3	4
Cos. Mask	[Home usage x Poor oil distribution]	5	5	0	0	4	5	5	2	2	5	4	4	4	4
Sex toy	[Couple's intercours x Poor fitting]	3	4	0	0	3	5	3	5	3	3	3	4	5	5
Shin Guard	[Tackle receiving x Injury and fracture]	4	5	0	0	5	4	2	2	5	3	2	5	3	4
Orthopedical soles	[Sole's cutomization x Time loss]	5	5	0	0	5	5	5	4	3	3	1	5	3	3
Earphones	[Sport and in mouvement x Bad fixation in ears]	0	5	0	0	2	5	3	3	2	3	2	5	5	4
Immobilization medical tool	[Medical radiography/scan x Low quality scans]	5	5	5	5	1	0	3	5	1	3	3	3	5	3
Hallux valgus orthosis	[Spreading toe in daily use x Lack of adaptation]	5	5	4	0	2	5	5	2	1	1	1	5	5	5
Video gaming joystick	[Professional gamer x Muscle disorders]	3	3	3	0	3	5	5	5	0	1	5	5	5	5
Fencing target	[Target's detachment x Point loss]	4	5	0	0	5	1	5	1	4	5	3	4	3	2
Artificial body part	[Attaching the body part x Time loss]	5	3	5	0	3	5	5	2	2	1	1	5	5	5
Bras	[Shaping the cup x Physical pain and skin irritation]	2	4	0	5	3	5	2	0	0	0	4	5	5	5
Tool's handle	[DIY usage x Pains in muscles]	2	2	0	0	3	2	5	2	4	0	1	5	3	2
Gas masks	[Military usage x Oxygen leakage]	5	5	0	0	2	5	3	3	2	4	2	5	4	5
Helmet	[Sport and military use x Skin irritation around face]	3	4	0	0	0	5	4	2	5	3	2	5	5	5
Connected watch	[Sport and in movement x Discomfort while moving]	4	5	0	0	0	5	2	2	0	3	2	5	3	5
Ski boots	[Long term use x Musculoskeletal Disorders]	5	5	3	0	4	4	5	3	3	3	5	5	4	4
Object's protection	[Carrying sensitive objects x Lack of full enveloping]	0	0	0	0	5	0	5	5	4	3	0	3	4	3
Prototyping objects	[Assembling fast prototype x Lack of deformable units/lack of creativity]	0	0	0	0	4	2	2	5	3	2	2	4	3	4
Decorative objects	[Reshaping a decorative object x Non-reshapable materials]	0	0	0	0	3	0	0	5	4	2	0	1	3	2

PART III. GENERAL DISCUSSIONS

In this part, we discuss the general consistency and impact of our methodological proposal, and interpret their implications and capacity for generalization.

Overall consistency of our methodological proposal

Specific aspects of each of the three methodologies we propose in this thesis are discussed in detail in their corresponding chapters. Here, we wish to discuss their overall consistency.

The set of three methodologies are: BMC-RID method for a wiser/more informed use of the Business Model Canvas (BMC), Design by Usage-based Experimentation (DUE) methodology, and Roadmapping Investments in TecHnology and Markets (RITHM) methodology.

These methodologies form a consistent whole as they share the same principles and tools for enhancing the key R&D activities of technology-oriented innovative startups. Indeed, they derive from the analysis of a common basis of existing knowledge in the fields of management of innovation, technology management, and engineering design.

The results obtained from deploying the methodologies demonstrate their pertinence as they address the following important issues:

- **The lack of systematic problem exploration from early phases of the product development process** is addressed through the support of practical tools. The task of problem exploration throughout the methodologies incorporates a set-based proposition rather than a point-based one. Innovative startups tend to adopt point-based design: a decision is made, it is executed, and then adjusted (pivoted) to circumstances. The issue with such approach is that it forces the startup to commit to one design solution and test it without understanding the problem that needs to be solved. By the time the startup realizes that serious adjustments (or pivots) are needed, it might be too late or costly to take a backward step. Therefore, a set-based thinking is more relevant to the context startup with limited time and resources.

- **The testing activity of an innovative technology is often fuzzy and starts with an opportunistic launching of tests without any clear focus**. In our approach, practical tools are provided in this work to define clear experimental objectives before testing begins. These objectives are indeed value creation opportunities

encompassing technology-market gaps that can be filled by the existing technology. Moreover, a systematic process structures the experimentation, with quantitative indicators built in.

- **The tests are not clearly planned nor prioritized**. Short-term planning of testing activities based on optimal tests is a new and relevant result enabled by the methodologies proposed in this thesis. This result can furnish important strategic information to technology-oriented innovative startups. In general, a startup, considering its limited resources and time, faces two main strategic challenges. First, an entrepreneur must focus on the right beach-head market (i.e., the easiest market to capture which is big enough to generate the cash flow necessary to access more markets). To reach this market, s/he must adopt and prioritize cost-effective experimentation strategies that enable the distance between the immature technology and the expected mature technology in this market to be reduced. Both challenges are addressed by the RITHM process and its optimization model to better steer R&D investment.

The pertinence of the methodological contributions of this thesis also depends on their ability to make an impact on startup ecosystems and/or to make a difference in terms of startup practice.

Impact of the proposed methodologies

We started this dissertation by outlining the problem of failure among startups. Following an investigation of 60 innovative startups, we demonstrated that startups fail because, at the value offer level, they lack the relevant tools to design and test their innovation and to rationally use resources. One possible research focus would have been to deploy the proposed methodologies across a panel of several startups, thus evaluating the impact of methodologies on the likelihood of success of these startups. Unfortunately, it was not feasible, given time constraints and accessibility questions, to test and verify such an assumption, which would require a longitudinal study and several years to guarantee the effective success of a startup. Moreover, such a study would have to take into account numerous parameters explaining the failure or success of a startup which are outside the scope of this research.

The way we chose to measure the impact of such methodologies was to implement and test them in a given startup. This test was made possible thanks to collaboration with a startup in Paris and two others in Montreal[17]. However, with these startups it

[17] The work in Montreal has been backed by the research award MITACS Globalink grant IT08957 in collaboration with the System Optimization Laboratory (SOL) of McGill University.

was neither easy nor possible to collect data post implementation in order to observe the impact of the methodologies on their practices in long-term.

A few weeks after starting deployment of RID methodologies, the following comments were noted

- ***"The Lean Startup approach is useful to develop a new mindset of scientific experimentation and the RITHM provides powerful complementary tools to clearly identify these experiments for the markets to be targeted in priority."*** (name withheld, Chief Commercial Officer of the studied startup in Paris).

- ***"This is an original and efficient method for systematically questioning the relevance of a technology regarding the identified markets"*** (name withheld, CEO of one of the two studied startups in Montreal).

This feedback shows a first attempt to change the mindset and practices of startups in terms of managing their R&D strategies. In the case of the Parisian startup, one of the unexpected practices was the use of the intermediary results of the methodologies to consolidate their application for a prestigious innovation prize. This methodological support allowed them to be listed as one of the three finalists of this prize in Paris area. This appears as a first satisfactory result.

However, we are aware that more accurate data must be collected to perform an impact analysis that shows to what extent time and other resources are saved once these methodologies are deployed. This data for the time being is not available and we are working to obtain it through different case-studies.

Regarding the differing ways of deploying the methodologies by startups, as chapter 2 showed, there is a risk that the proposed methodologies may not be used or they may be misused. This risk is of course never zero because the use or misuse of a method or tool depends on multiple factors such as the awareness of entrepreneurs, their experience, and willingness. These constraints are inevitable and vary from one startup (or one entrepreneur) to another. But, as discussed throughout this thesis, regardless of the personality and skills of entrepreneurs, the commonest reasons for not using (or misuse) the existing methods are the following:

- inherent deployment difficulties (e.g., complex, unpractical and cumbersome tools);
- qualitative outcomes that fail to support an entrepreneur's decision-making;
- lack of rigor and coarseness of some approaches;

- lack of courage in rigorously deploying methodological approaches in long-term.

Our methodologies are designed to take these difficulties into account, yielding tangible results by the use of practical and rigorous tools. Of course, these results will need further refinement in future tests.

These tests can be conducted with startups or even by simulating the situation of a startup. Interestingly, towards the end of this PhD research, a number of startups and innovation experts asked if our methodologies had been deployed to our own startup project for commercializing our methodologies to see what should be tested and commercialized first.

Initial research suggests that there are a number of potential markets in which the methodologies can be commercialized. For instance, innovation training is one of these markets that can target entrepreneurs, company executives, innovation managers, consultants or business coaches who are looking for differentiating and quantitative methods. Another potential market is the innovation consultancy services for startups and incumbent industries that are looking for methodologies to help them develop the maturity of a core technology. The latter can particularly bring real value to companies that have already patented a technology. Even though several potential markets have been considered, it is necessary to thoroughly explore the value creation opportunities (or market gaps) with regards to these markets. The identification of these opportunities will enable effective roadmaps that aim at making the methodologies mature for profitable markets to be identified. Finally, we consider that the mere interrogation of experts and startups regarding the commercialization of methodologies indicates that they have resonated well with them.

Application and adaptation to other contexts

The proposed methodologies are adapted to the case of technology-oriented innovative startups and are geared toward their well-known specificities (i.e., dealing with short-term development processes, overcoming entry barriers, securing limited resources, constantly looking for fundraising and increased cash flows, making the company attractive for acquisitions (or an *exit event*), and the different structure of R&D activities compared to larger firms).

Compared to a large incumbent firm (i.e., one that already operates in the industry), in a startup the technology leadership, R&D priorities and positioning as well as criticality of generating increased cash flow are completely different. However, despite these striking differences, recently most of a startup’s specificities are shared by large firms.

For instance, some large firms are now taking initiatives that mimic the agile processes under which startups operate. These initiatives include, among others: creating innovation and experimentation labs, crowdsourcing of ideas among startups, and also adopting intrapreneurial techniques[18]. For these reasons, the proposed methodologies can be easily implemented in large firms, and in particular to their existing intrapreneurial projects.

However, as mentioned earlier in this thesis, the methodologies are suitable for a project where some data has already been collected about markets, and the technology is at least at Technology Readiness Level (TRL) 2[19]. It is therefore complicated, for the time being, to adapt the current methodologies to a completely immature technology where product development has not yet started and/or very few data sets have been collected.

From the perspective of data feeding of the methodologies, we are convinced that they can yield more accurate results in large incumbent firms. Most often, large firms have a culture and background of testing. The input data to feed the testing models are thus more easily available thanks to historical testing data, providing that the data collection and its traceability were relevant.

Additional applications of the proposed methodologies can be envisaged within other types of organizations such as non-profit organizations and also academic entities. Non-profit organizations do not aim at making profit or at taking market shares, but they innovate on products and services intended to create high social values. The methodologies can be applied in this context as they are driven by the usefulness of an innovation and its ability to solve people's problems rather than merely focusing on profitable markets. Even though minor modifications must be made to the market variables, the generic models of the methodologies enable non-profits to effectively invest in social innovation.

Universities and more generally academic entities can use the proposed methodologies for the purpose of fostering and accelerating their process of technology transfer (i.e., transferring knowledge to the industrial and business world mainly through Open Innovation strategies). Beyond the direct relationships with industries, universities may support the creation of spin-offs based on internally developed know-how or technology. The methodologies of this thesis will therefore be attractive for the technology transfer offices of universities to help them diagnose the

[18] For instance, Google and 3M are known to allow their workforces to spend one day per week on an innovative project that is unrelated to their daily work (this is called the "20% Rule"). Adobe has also introduced a set of processes to foster innovative projects via incubation of projects and the support of "entrepreneurs (or designers) in residence".
[19] i.e., the technology concept has been formulated.

market potential of a technology and to evaluate the required R&D efforts to make a technology mature for its promising markets.

Finally, the current methodologies do not systematically cover the design of an innovative product-service bundle, nor of a process innovation[20]. Indeed, when a technology startup shifts from commercializing a good to the provision of a service, the entire product life-cycle is managed differently and in a more complex way. These complexities will obviously affect the existing R&D and experimentation processes of the startup. Therefore, the proposed methodologies must undergo appropriate changes to be able to deal with the new situation. A hybridization of the methodologies with methods focusing on process innovation can be considered.

Academic contributions

From a research perspective, the contributions of this thesis extend the classical entrepreneurship methods and tools as they provide new quantitative methods to enhance innovation. Researchers may thus find interest in harnessing these contributions in further research.

The proposed methodologies are largely derived from the Radical Innovation Design® (RID) methodology, but provide additional tools to design relevant experimentation and business strategies, especially in the case where a technology may be applied to several activity fields – and additional markets. Further research on the RID methodology is in progress. In this way, the results obtained from the current thesis will directly input into this research.

From an educational point of view, the proposed methodologies can be taught and transferred in the form of workshops, seminars or training sessions. At the time of writing, the methodological approaches proposed in this thesis along with the Radical Innovation Design® methodology have been selected by the doctoral schools of Université Paris-Saclay to be integrated as part of an R&D training program, called Technology-Innovation-Startup (TIS)[21]. The idea behind this program is to consider PhD research as a technology and to identify, through a five-day workshop with PhD students, use-cases and profitable markets for their research. The DUE and RITHM methodologies are used in these workshops to usefully develop the analogy of a PhD with a startup or company technology. At the end of these workshops, PhD students acquire new skills to identify possible applications, patents, and arguments regarding

[20] The process (or organizational) innovation consists in changing the ways a company operates its business processes. It is not perceived by customers unless its outcomes consist in lower costs and prices, or improved products or services.
[21] Details about this program can be found at http://www.adum.fr/psaclay/formations.pl?mat=173236

their research work whether they wish to work in an existing company or plan to launch a startup.

Contributions to innovation ecosystem and industries

The Urban-Centered Innovations (UrCI) selection and evaluation tool, detailed in chapter 1, has been adopted by the Parisian Urban Lab as a check-list to interview startups that provide an experimentation project. This adaptation was undertaken by one of the agents of the Parisian Urban Lab. In fact, integrating a new tool to the existing selection and evaluation processes of the City of Paris was complex insofar as such a tool must comply, among other factors, with current public procurement regulations. In doing this, the Urban Lab has developed a new usage of this tool.

In the context of technology-oriented innovative startups, several contributions in the form of practical and rigorous tools have been made throughout the three proposed methodologies in this thesis:

- The BMC-RID methodology (as a hybridization of the Business Model Canvas (BMC) (Osterwalder and Pigneur, 2010) with the RID methodology (Yannou et al., 2011)) is proposed to systematically explore relevant problem seeds, that we call value buckets, before starting to fill in business model canvas. To progressively transform these problem seeds into relevant solutions, the BMC-RID proposes a set of quantitative proofs that monitor the maturity of the value offer and other BMC components.

- The process and deliverables of the DUE methodology are structured and practical. This extends beyond the principles of the Lean Startup (Ries, 2011), the testing process of the Value Proposition Design (Osterwalder et al., 2015), and the learning cycle of Thomke (Thomke et al., 1998). Indeed, relevant decision-making supports are provided by the DUE prior to generating test hypotheses and building physical and/or virtual models for testing.

- The RITHM process and optimization model provides decision supports in terms of allocating resources to those experiments that are cheaper, faster, and more efficient in reaching the “low-hanging fruit” (or the most profitable and accessible markets). This is a new quantitative result which differs from the existing technology roadmapping tools such as incidence matrices or Customer-Focused Technology Planning (CFTP) techniques (Paap, 1994).

Henceforth, startups can make sound investment roadmaps to mature their technology in order to reach the most profitable markets. By doing so, startups use

their time and other resources in a more rational and organized way. Moreover, the results of implementing RITHM can help startups consolidate their fundraising applications, as they are asked to provide tangible elements on their target market(s), technology maturity roadmaps, and the funds needed to reach these targets.

Mentors and advisors of startups are also concerned by such results. Indeed, thanks to these tools, they can better guide startups and become more efficient in their advisory/consultancy tasks.

From an intrapreneurial perspective, the contributions of this PhD may provide support for the decision-making of intrapreneurs or of “entrepreneurs in residence” in large incumbent firms. These firms seek to value their existing knowledge (e.g., in applied research and technology development projects or patents), leading to them taking intrapreneurial initiatives. Moreover, they are engaged in more open innovation strategies through different mechanisms such as crowdsourcing or technology acquisition which is characterized by a complex process and involves important transaction costs[22].

The technology acquisition process is supported by technology scouts (an employee of an acquirer company or an external consultant (Rohrbeck, 2010)) who may also benefit from the contributions of this PhD. Indeed, the mission of technology scouts consists not only in scouting, but also in evaluating, matching and securing successful execution of acquisitions. Currently, their task of matching between external technologies and internal requirements is more often aided by technology roadmapping (TRM) (Phaal et al., 2004). In this context, the DUE and RITHM approaches can be used as complementary approaches to identify the effort required to make the acquired technology mature enough so that it can reach the most profitable markets.

Future validations and directions for future work

The specific limits and further validations of each contribution of this thesis are detailed in the corresponding chapters. However, some general limits of this research as well as the directions for future work must be mentioned:

- The overall impact of the proposed methodologies on reducing the likelihood of failure and increasing the success of urban-centered startups and ultimately local economic growth cannot be easily verified. This needs a large longitudinal

[22] Transaction costs are the expenses incurred during trading on top of the price paid.

study that exceeds the scope of the current thesis, but could be the focus of future research.

- Because of the chaotic environment of a startup and its shortage of time and resources, the use of "investigation methods" prior to experimentation might appear to be cumbersome, *unlean*, and delaying the startup progress. Therefore, it must be demonstrated through further research that it is worth spending more time defining the right gaps and planning cost-effective experiments instead of launching loop-based and uncertain tests.

- In the same way, filling in matrices manually and validating data from different sources might take between several weeks to several months, depending on the startup's resources and technology maturity. It would have been more efficient to have access to reference sources via an intelligent system crunching data from them. Therefore, in future research the efficiency of data feeding and validation must be enhanced.

- Because of the limited duration of a PhD project, we were not able to deploy the proposed methodologies to other contexts of startups (other technology-based or service startups). The purpose of such deployment would be to verify and validate the robustness and adaptability of the methodologies.

- Finally, with regards to the previous point, at this stage we are not able to say if our methodologies should be applied by highly-skilled consultants in early development phases of technology startups, or if we can propose a lean, simple, and computational solution to be independently used by the startupers themselves.

References of the general discussions

Osterwalder, A., and Pigneur, Y. (2010). *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. New Jersey, United States: Wiley. 9780470901038.

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., and Papadakos, T. (2015). *Value Proposition Design: How to Create Products and Services Customers Want*. New Jersey, United States: Wiley. 9781118968055.

Paap, J. E. (1994). Technology management and competitive intelligence: new techniques for a changing world. *Competitive Intelligence Review, 5*(1), 2-4.

Phaal, R., Farrukh, C. J., and Probert, D. R. (2004). Technology roadmapping—a planning framework for evolution and revolution. *Technological Forecasting and Social Change, 71*(1-2), 5-26.

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. New York, United States: Crown Publishing Group. 9780307887917.

Rohrbeck, R. (2010). Harnessing a network of experts for competitive advantage: technology scouting in the ICT industry. *R&D Management, 40*(2), 169-180.

Thomke, S., Von Hippel, E., and Franke, R. (1998). Modes of experimentation: an innovation process—and competitive—variable. *Research Policy, 27*(3), 315-332.

Yannou, B., Jankovic, M., and Leroy, Y. (2011). *Empirical verifications of some Radical Innovation Design principles onto the quality of innovative designs.* Paper presented at the DS 68-1: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design, Vol. 1: Design Processes, Lyngby/Copenhagen, Denmark, 15.-19.08. 2011.

General conclusion and perspectives

Summary

Transforming a core technology into a viable business is a demanding and complex task for startups evolving in the dynamic setting of multi-stakeholder environments. In this context, Research and Development (R&D) may require greater investment, as the exploration of the technological landscape and unknown customer needs is a time- and resource-consuming task. There is therefore a need to conduct extensive tests (or experiments) to gather satisfactory proofs of concept and proofs of value, thus reducing uncertainties before the launch of the product on the market. To meet these challenges, effective R&D strategies adapted to the context of technology-oriented innovative startups are needed.

To address this need, several methods and tools already exist. The Business Model Canvas (BMC) and the Lean Startup are two of the best known. However, despite the existence of these approaches, our observations of 60 innovative startups, in the context of a City of Paris initiative, revealed that they have no practical tools for specifying and planning their R&D investment for maturing their core technology through experimentation. This weakness can in turn result in an important waste of scarce resources and ultimately in a startup's failure. Based on these observations, we propose in this PhD thesis a set of practical tools intended to meet this challenge.

In light of the identified gaps in the existing methods and tools, three research questions are formulated. These questions are addressed in chapters 3, 4 and 5 of this dissertation.

In chapter 3, a more rational use of the BMC is proposed prior to conducting experiments in the context of technology-oriented innovative startups. To make a wiser/more informed use of the BMC, we propose a hybridization of the BMC and the Radical Innovation Design® (RID) methodology (called BMC-RID) together with a set of practical and quantitative tools. These tools enable experiments to be conducted on a justified value offer. The BMC-RID methodology thus enables the diagnosis of a value offer and its associated businesses.

In chapter 4, the tools of the BMC-RID are integrated into a comprehensive methodology called Design by Usage-based Experimentation (DUE). This methodology contains a structured process, a set of tools, algorithms and deliverables. The DUE process identifies a set of technology-market gaps. The latter are quantified by linking the promising markets to the main properties of the technology in a series of matrices.

Then, the identified gaps serve as a target to define relevant testing hypotheses and actions. A set of tools is therefore proposed to structure and organize experimentation scenarios. However, to better allocate a startup's resources to the most cost-effective experiments, a third methodology is proposed in chapter 5.

Once the technology-market gaps have been identified, the Roadmapping Investments in TecHnology and Markets (RITHM) methodology establishes a link between experiments, their lead-time, their cost and their ability to improve the maturity of a technology, thus reducing the gaps. RITHM then proceeds to find a representative set of Pareto-optimal experiments on the core technology. Finally, it quantifies trade-offs in satisfying different optimization objectives (i.e., minimizing cost, lead-time and the technology-market gaps). The optimization outcomes indicate a technology with properties that are mature enough to meet the most profitable markets. Based on these results, more realistic roadmaps can be outlined compared to traditional technology roadmapping, as our methodology precisely models technology properties to outperform as well as the related development/experimental costs. This methodology adopts a general optimization scheme to clearly decide which subset of markets must first be targeted.

The three methodologies are applied to the case of a startup designing a shape-changing technology. The results show that these methodologies provide practical tools that may arouse interest or significantly support the decision-making of different stakeholders from academia and from the innovation ecosystem.

Perspectives

The research work was a satisfactory first step to put innovation into equations and to optimize the R&D process of technology-oriented innovative startups. There is still need for further research to validate and refine the proposed methodologies. However, as a first line of work to deal with the little-explored field of innovation processes of startups, interesting primary results have been delivered to the startups studied. To develop these results, four research perspectives can be envisaged.

The first perspective is to communicate these results to innovation ecosystems and to raise their awareness regarding the importance of using rigorous methods to evaluate, experiment, and make mature a technological innovation. Public organizations that fund and support startups could instill and diffuse such innovation attitudes and play an important role in educating startups. Indeed, most often these organizations invest in startups without necessarily questioning the return on investment. A recent French book (Menet and Zimmer, 2018) raised the alarm on this matter by recalling the important number of failures among startups. The conclusion

is that there is a need for more systematic and method-based innovations to create useful innovations. The authors refer to rigorous problem-based methodologies like Radical Innovation Design® as an example of one way to proceed.

The second perspective consists in experimenting the proposed methodologies with two different cohorts of similar startups in order to compare results of the experimental and control groups. A partnership with an innovation incubator could help deploy such tests and validate the methodologies. However, this is fraught with potential complications and would necessitate finding similar groups of startups and entrepreneurs, and running tests over several months with them. As discussed before, such tests must be conducted very carefully to avoid coarse and inaccurate results.

The third perspective deals with automatizing the existing tools, along with an acceleration of the data feeding and validation processes. To increase the speed of data processing and the accuracy of the optimization results, machine intelligence and other related technologies should be used. The objective of such automated learning will be to extract knowledge from appropriate fields such as physics, psychology, sociology, and medicine. To collect and extract this knowledge, software architecture can integrate ad hoc software modules (such as text, image, and video frame processing solutions to improve the accuracy of investigations prior to experimentation).

Finally, a fourth perspective is related to deploying the proposed methodologies to other startup contexts. One idea could be to formulate the hypothesis that the whole proposed methodologies are a core technology to be commercialized by a startup. In this context, we plan to apply the methodologies in our own startup. In such a case, the ultimate validation of this PhD work would be the success of this startup.

Reference of the conclusion and perspectives

Menet, N., and Zimmer, B. (2018). *Start-up, arrêtons la mascarade: Contribuer vraiment à l'économie de demain*: Dunod. 2100773313.