In vivo in situ experimentations projects by innovative cleantech start-ups in Paris

Alborz Bekhradi, Bernard Yannou, François Cluzel, Frédérique Chabbert, Romain Farel

In vivo in situ experimentations projects by innovative cleantech start-ups in Paris

Alborz Bekradi[1, 2], Bernard Yannou[1], François Cluzel[1], Frédérique Chabbert[2] and Romain Farel[3]

[1] Ecole Centrale Paris, Laboratoire Genie Industriel, Chatenay-Malabry, France

[2] Department of Economic Development of the City of Paris, Paris, France

[3] PS2E Research and Education Institute, Les Loges-en-Josas, France

Abstract: Cities play an essential role in facilitating and supporting the real-world experimentations (for instance in public spaces with real users) of innovative products and services in the field of clean technologies. In this respect, the City of Paris has implemented an experimentation mechanism to help innovative start-ups improving their solutions and robustifying their business models in a multi- stakeholder eco-system. Nonetheless, a primary investigation demonstrated that the efficiency of these in vivo in situ experimentations have means of being improved.

To deal with this issue, the current paper proposes a critical review and a characterization of the existing projects related to clean technology and sustainability themes. A study over 25 experimentation projects results in identifying matches and mismatches between the expectations and the obtained results of tests by innovative start-ups. We have statistically demonstrated that the most important purpose of running experimentation projects by start-ups is to test and build a relevant "stakeholders network" around their businesses. Furthermore, we have assessed the influence of these experimentations on the design of innovative products.

1. 1. Introduction

Cities represent 2% of the surface of the planet; 50% of the world population is urban, and this population is growing [1]. Today, cities are responsible for 75% of the overall world energy consumption [2]. Thus, global energy issues are of paramount importance for cities, including the City of Paris, which aims at reducing by 25% its emissions of greenhouse gases and energy consumption by 2020 [3]. In this context, clean technology start-ups attempt to provide innovative solutions to address these major environmental challenges.

Clean technology or cleantech is a general term used to describe products, services or processes that use less material and/or energy (requiring as few non-renewable resources as possible) and generate less waste or pollution. A clean technology start-up can be defined as a new venture engaged in developing and marketing products, services or processes that reduce negative environmental impacts [4]. These companies are constantly looking for a viable business model around clean technology innovation, which may include various sectors and applications.

In Paris, there is a significant number of innovative clean technology start-ups [5] providing innovative design solutions. These solutions are for instance: buildings' energy efficiency software using a playful approach helping building occupants to reduce their energy consumption [6]; or, a smartphone application, which rewards, by gifts vouchers, citizens' environmental-friendly behaviour, such as waste recycling or using shared or personal bikes [7] (see Figure 1 for examples of these solutions).

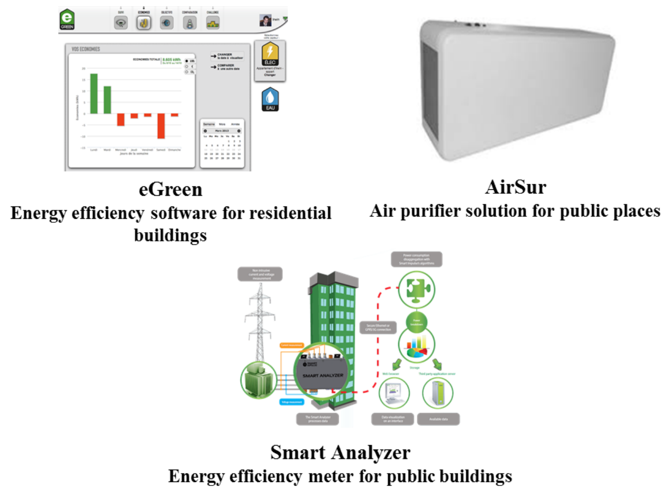


Figure 1. Innovative cleantech design solutions experimented in Paris [8].

Given the novelty of these solutions on the market, there is an important degree of uncertainty regarding their usefulness and capacity to address environmental challenges as well as their technical robustness, and more importantly their potential to succeed on the market. Therefore, these innovative products and services need to be accurately tested, evaluated and validated in real usage situations before their launch on the market. In parallel, the potential public buyers of these solutions should have access to relevant decision-making elements regarding the usefulness, technical feasibility and value creation of these design solutions for the city and citizens.

Thus, in order to help stakeholders having access to reliable decision making elements, the City of Paris has launched an open innovation policy that calls upon the entire Paris region to play a key role in business development and improving public services. In most cases, innovative businesses have difficulties finding their first customers. Once the phase of R&D of the product or service is completed, it then needs to be approved for use in live conditions. In order to assist innovators in this crucial step, in 2010 the City of Paris mandated its innovation agency (Paris&Co) [8] to make all public spaces (e.g. streets, squares, gardens, public buildings and undergrounds) available for *in vivo in situ* experimentations. Innovative start-ups, receive supports in developing an experimentation protocol, identifying the relevant experimentation site and obtaining the required authorizations as well as public financial supports. The main objective of these experimentation projects, commonly named *in vivo in situ* or urban experimentations, is to test and validate prototypes of these innovative solutions in live conditions directly with the potential users and residents of Paris. However, a primary investigation among clean technology start-ups that have previously carried out an *in vivo in situ* experimentation with the City of Paris has led us to observe that these experimentations have means of being improved. Indeed, it seems that there is a lack of scientifically reliable analysis on the experiments' feedbacks and efficiency. Therefore, this paper will first attempt to characterize *in vivo in situ* experimentation projects. Subsequently, we identify the reasons of why some experimentation projects do not always meet their targets and then we will provide recommendations to improve the efficiency of these experimentation projects.

The present research begins with a literature review in terms of experimentation and validation of innovative products and services in real conditions. In Section 3, the research hypotheses are described. Section 4 consists in describing the research methodology of this paper. Section 5 describes the data collection and validation process. In Section 6, the obtained statistical and qualitative results are presented. Finally, we outline a set of recommendations to improve the efficiency of these experimentation projects.

2. real-world experimentation and validation of innovative product-service-systems

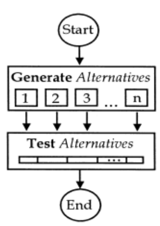
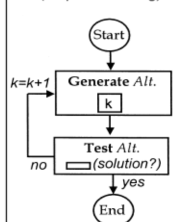
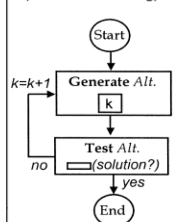
The test and validation of an innovative design solution in real usage situations is vital to reduce the uncertainties and unknowns in the design and the launch of a system (product and/or service and/or a business model).

Despite the advantages (i.e. reducing the costs of experiments (see [9])) of using computer-aided simulations to evaluate a design solution, the realiability of physical models can not be ignored given their efficiency in knowledge generation [10, 11]. More particularly, in the case of innovative design solutions where there are any existing feedbacks on the design solution, it is not possible to carry out reliable CAD simulations over solution's performance.

The literature behind experimentation methods and technologies shows, through genuine industrial cases, that there are different techniques to perform efficient experiments by minimizing the number of experiments and maximizing the learning. Thomke et al. emphasize in [12] that defining a relevant experimentation strategy can significantly affect the effectiveness of firms' innovation process and their relative competitiveness on the market. Table 1 represents a comparison between different experimentation strategies for which different learning modes and attributes are identified.

The purpose of Design of Experiments (DOE) or experimental design is also to minimize the time and cost of obtaining an accurate reliable information. The experimental design represents a series of experiments organized in advance to determine the effect of factors (or inputs) on response (output) of the system with minimum cost and time for a given accuracy [13]. The DOE process consists of first; defining the problem, second; determining objectives, third; estimating the values of levels and forth; running the experiments and analyzing the collected data.

Table 1. A comparison of different experimentation strategies [12]

Experi-mentation Strategy	(a) Parallel Experimentation	(b) Serial Experimentation *(Rapid Learning)*	(c) Serial Experimentation *(Minimal Learning)*
			
Learning between periods	None	50% reduction of search space after each period	Eliminate only un-successful alternative after each period
Expected # of periods	*1*	$\log_2 n$	$\frac{n+1}{2}$
# of trials per period	*n*	*1*	*1*
Expected # of trials	*n*	$\log_2 n$	$\frac{n+1}{2}$
Attributes	Highest cost Fastest speed	Lowest cost Medium speed	Medium cost Slowest speed

The general process of experimentation in a given organization [9, 14] (as depicted in Figure 2) begins with designing a solution based on design requirements and learning. The results of analyses over the collected data generate learning and enable to validate the solution or to reiterate the test.

This general process is however not directly applicable to the case of *in vivo in situ* experimentation projects insofar as they involve various parameters regarding for instance real usage situation, stakeholders and their expectations. In the rest of this paper we will discuss the general process of experimentation projects as well as the characterization of these projects.

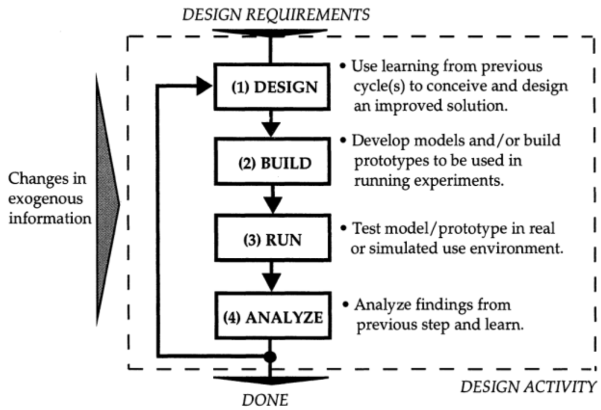


Figure 2. General process of organizational experimentation (from [9])

3. Research Hypotheses

Based on primary field investigations over the cleantech start-ups' practices in terms of experimentation of their innovative solutions, we describe in the following 3 research hypotheses:

Hypothesis 1: Start-ups aim at weaving links with other public and private stakeholders through *in vivo in situ* experimentation projects

The innovation eco-system around innovative start-ups is a multi-stakeholder environment where start-ups constantly look for opportunities to introduce themselves to new markets through partnerships with other stakeholders and by doing so finding their first customers. Therefore, *in vivo in situ* experimentations serve more to convince stakeholders of the value creation and usefulness of their solutions, rather than testing and validating solution's performance.

Hypothesis 2: Start-up companies cannot always meet their targeted objectives

Mismatches between the experimentation results and hypothesis seem to confirm that there are on the one hand, failures, dysfunctions and dissatisfactions of involved stakeholders and on the other hand, unexpected satisfactory results to be analyzed.

Hypothesis 3: experimentation influences the design process of innovative products

The learning phase of experimentation must allow companies to improve their prototype before its launch, which might help them to generate new ideas for NPD (New Product Development) by investigating the usage situations through experimentation. This statement is not yet proven through a proof review of the existing experimentations and is worth studying.

In order to study the validity of the above-mentioned hypotheses, a relevant research methodology must be outlined.

4. Resarch Methodology

For illustrating the general process of test and validation of innovative design solutions in real usage contexts, an experimentation protocol must be first defined. An ontological model is therefore defined inspired by [14], over real-world experiments with multiple stakeholders (see Figure 3). Starting from the design specifications of a product-service-system, experimentation expectations must be identified and prioritized in terms of their importance and test feasibility, by taking into account the stakeholders' expectations. Then, the experimentation project is designed by taking into account the stakeholders' expectations and constraints. Before running tests, the prototype might be adapted or adjusted to the terms of the designed experimentation project. During tests a systematic observation process is necessary. After and/or during the observations, data is collected, processed and test hypotheses are accepted or rejected. Finally, learning from experimentation must be captured [14] for the start-up in terms of refining its solution, having access to a more important stakeholder network and iterating (e.g. with a new prototype and/or based on a new observation and evaluation method).

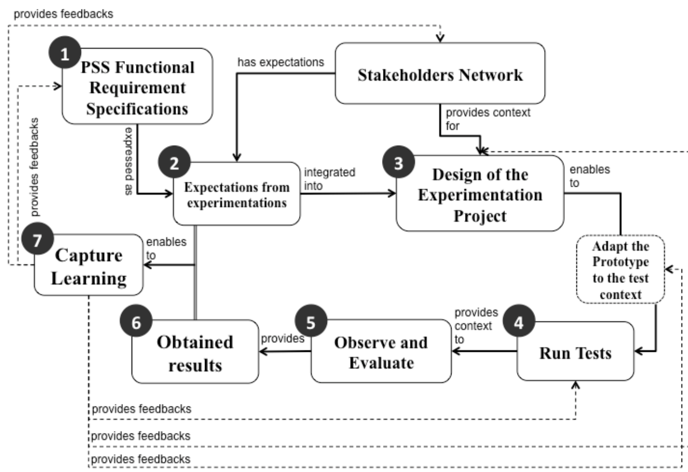


Figure 3. Proposition of a general experimentation protocol.

Based on this ontological model, we intend to characterize the experimentation projects of innovative clean technology design solutions and also to identify how it is possible to improve projects' efficiency according to this general process. To achieve this target, defining an organized step-by-step methodology is necessary. Since the purpose of this research is to characterize experimentation projects, the identification of a set of criteria of analysis seems appropriate, to the extent that without characterizing experimentations' features we will not be able to investigate the possible ways of improvement of these projects.

1. The methodological steps are defined here as the following:
2. Identification of criteria, which characterize the experimentation projects' context and the experimented solution;
3. Categorization of projects following a combination of identified criteria;
4. Definition of expected (before the experimentation) and proven (after the experimentation) indicators and comparing them through statistical tests;
5. Assessing learning from experimentation and influence on the design of products;
6. Analyzing the reasons of dissatisfaction of stakeholders and low efficiency of experimentation projects for innovative start-ups;
7. Proposition of recommendations to improve the efficiency of experimentation projects.

5. Data gathering and quality validation

We first review the existing experimentation projects' reports that have been provided by cleantech start-ups either at the end or in the middle of their projects. These reports represent a very useful and valuable material to be thoroughly analyzed. However, most often there is a lack of accurate information on the companies' expectations, obtained results of trials as well as the influence of experiments' results on the design of innovative solutions. Therefore, as a second step, a field investigation is necessary to understand the real claims and the obtained results of tests. A set of face-to-face interviews and teleconferences are conducted with cleantech start-ups to collect the missing data and to validate with them the retrieved information from experimentation reports. Besides, other stakeholders such as incubation and experimentation experts in the City of Paris are interviewed.

Investigations over the cleantech start-ups, which have carried out experimentations in Paris, enable us to create a database containing 25 distinct experimentation projects, performed by 25 innovative start-ups. It is worth noting that for the time being, there are only 25 start-ups in the field of clean technology that have already finalized their experimentation projects in Paris.

6. Results

The proposed research framework has allowed the building of a reading grid for 25 experimentation projects. The study over this reading grid has a twofold objective: first, to categorize these projects, second, to identify if the expectations have been met at the end of the project and if so to what extent.

6.1. Identified criteria of analysis

Given the lack of a generally acknowledged definition of clean technologies' categories according to [15], we do not intend here to categorize the 25 existing projects in terms of their cleantech application or technology. Besides, in this research the evaluation and observation methods are not characterized, given their variability according to project's nature.

Therefore, in this research we identify the attributes or the criteria of analysis, which enable to better characterize the context of projects and the solution's characteristics. We identify thus 2 types of criteria in the following: first, the characterization of the general context of *in vivo in situ* experimentation and second, the solution's attributes.

Characterization of the general context of in vivo in situ experimentations

Research works in terms of characterizing usage contexts (see for example [16]) as well as in terms of usability tests (for instance [17]) study the context of users' tests of innovative solutions. Authors have identified a trio between the product, the user and the usage situation. In this research, we apply this concept to the case of *in vivo in situ* experimentations by identifying: Prototype (**P**), Test User (**U**) and Test Situation (**S**). However, given the existence of multiple stakeholders playing an important role in these experimentations, we also add the experimentation partners or stakeholders (**A**) as the fourth criterion (see Figure 4).

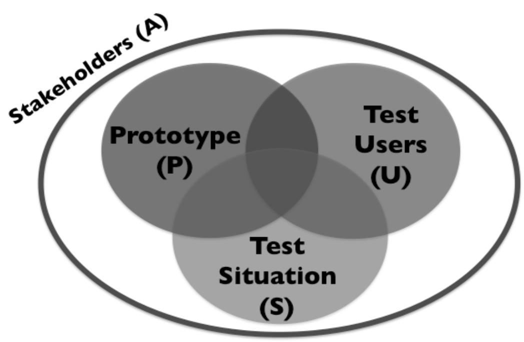


Figure 4. *In vivo in situ* experimentations context.

For each criterion, a set of modalities is identified. Table 2 illustrates the identified modalities for the P-U-S trio.

It must be noted that obviously in real-world experimentations simulated users (u3) and simulated usage situations (s3) cannot be gathered together. Here, we keep these modalities for the sake of completeness.

Table 3 illustrates the identified existing stakeholders involved in experimentation projects. These stakeholders can be legal persons, companies or individuals.

Table 2. Prototype, Test-Users and Test Situation.

Criterion	Modality	Description
Prototype (P)	**Physical prototype (p1)**	A materialized and functional prototype
	Software prototype (p2)	A functional prototype of a software or tablet/smartphone application
	Service prototype (p3)	An immaterialized service prototype
Test-User (U)	**City's residents (u1)**	Citizens who participate in tests
	Employees of the experimentation site or the start-up (u2)	Employees of the experimentation site or the start-up who participate in tests (in-field or in distance)
	Simulated users (u3)	*Test-users who simulate usages*
Test-Situation (S)	**Public and semi-public space (s1)**	Public urban spaces, e.g. streets and gardens as well as semi-public spaces e.g. shopping centers
	Internal usage situation (s2)	Inside a residential, administrative or industrial building
	Simulated usage situation (s3)	*Simulated usage situation, for instance in a usage lab*

Table 3. Involved stakeholders.

Modality	Description	Example
a1	**Test facilitator and coordinator**	Department of Economic Development of the City of Paris and Paris&Co agency [8]
a2	**Experimentation site manager**	Manager of a public building
a3	**Technical and operational support for running tests**	Operational departments of the City of Paris
a4	**Public investor**	Bpifrance (France's public investment bank)
a5	**Observation & evaluation expert**	Consulting or design firm
a6	**Buyer**	Public or private purchaser
a7	**Purchasing advisor**	Public or private purchasing advisor
a8	**Incubator**	Cleantech incubator of the City of Paris

For each experimentation project, a combination of involved stakeholders is to be identified. In this research, we do not attempt to identify the degree of involvement of stakeholders as well as their interrelationships. For the time being, we simply identify a list of the involved stakeholders, which is validated by experimentation experts.

Characterization of the solutions' attributes

In order to characterize solutions' attributes, the maturity levels of a design solution must be identified based on a relevant scale. Since the marketing functions of a design solution are tested through experimentations, inspired by TRL (Technology Readiness Level) and MRL (Marketing Readiness Level) [18] we propose a new scale called MML (Marketing Maturity Level) (see Table 4). This parameter is more understandable to the interviewed start-ups comparing to other maturity level indicators such as System Readiness Level or Innovation Readiness Level [19].

Table 4. Marketing Maturity Levels of product and/or service.

Phase Title	Description
MML_1: Concept	*Research project, basic sketches of the product or service*
MML_2: Development	*CAD designs, computation modules*
MML_3: Basic prototype	*Basic mock-up to be tested inside the labs*
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	*Existing on the market and widely used by customers*

The value of MML is reported before (*MML*) and after the experimentation (*MML'*), in order to outline the progress of a start-up in terms of its solution's maturity.

Test and validation of an innovative design solution is generally performed in the phase problem solving [20]. In the case of 25 analyzed experimentations, start-ups tested a functional prototype of their product and/or service. Therefore, the MML level of the analyzed solutions is at least equal to 4. As shown in Figure 5, we can also question the possibility of test and validation in early stages of product development i.e. in the phase of problem setting.

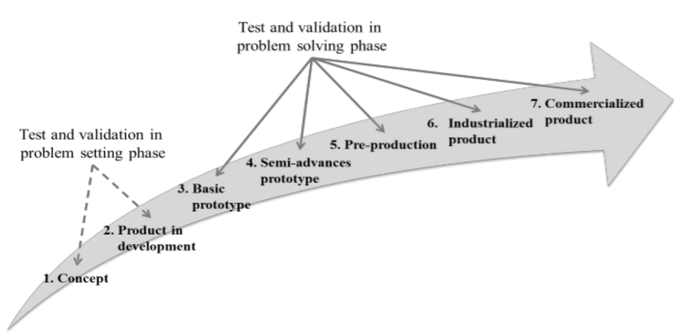


Figure 5. Experimentation in problem setting and problem solving phases.

This kind of experimentation can also be done in real usage situations without developing a costly prototype. The main purpose of this kind of test and validation is to investigate and explore the world of problem where there are sufferings (or, pain points) to be identified [21].

Besides the maturity level of the solution, its marketing model is worth to be analyzed. In Table 5, these marketing models are identified. The public procurement contracts are identified as "B to P", where the buyer of the solution is a public stakeholder and the purchasing mechanism due to the legal aspects of organizing public tenders is more complex comparing to "B to B" or "B to C" solutions. An example for a B to P model is the energy efficiency software designed for public buildings and helping public stakeholders to identify the most efficient consumption scenarios. In Table 5, we also propose "B to P to U" marketing model for instance in the case of waste sorting and management software directly involving citizens, where the first buyer of the solution can be a public actor who then addresses the solution to citizens.

Table 5. Marketing models of the analyzed innovative design solutions.

Marketing Model (M) modality	Definition
B to B	Business to Business
B to C	Business to Customer
B to P	Business to Business (via a public contract)
B to B to C	Business to Business to Customer
B to P to U	Business to Business to User (via a public contract)

6.2. Categorization of projects

Following a combination of the identified modalities, we are now able to categorize projects by creating customizable clusters. Figure 6 enables visualizing a given cluster of experimentation projects regarding the identified criteria of analysis. A Parallel Coordinate Plot (PCP) visualization tool is developed to better illustrate the whole 25 projects and their characteristics. For instance in Figure 6, it is possible to identify the number and identity (only disclosed to the involved stakeholders) of cleantech innovative solutions where the experimented prototype was a software prototype (p2), tested only in internal usage situations (s2).

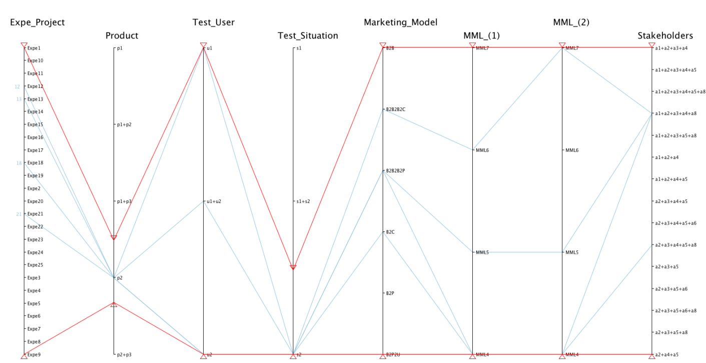


Figure 6. PCP visualization of a given cluster over 25 experimentation projects (higher resolution version in Annex A).

This categorization tool is extendable to more than 25 case studies and enables stakeholders to have a clearer vision of the cleantech experimentation projects by manually identifying the combination of modalities.

From this cluster, we can also assess the number of solutions where there was a greater Marketing Maturity Level (*MML*) at the end of the experimentation (i.e. *MML – MML'* > 0).

The first objective of this research was to characterize and also to categorize cleantech experimentations. In the rest of this paper, we will investigate the expectations and obtained results of experimentation projects and we will also discuss the possible improvement ways of cleantech experimentations.

6.3. Definition of indicators over the expectations and the obtained results and their comparison

Beyond testing and validating solution's performance in terms of its ability to respond to given usage situations, its technical efficiency and the expected profitability for customers and for the company [22], the capacity of weaving a canvas with other stakeholders is crucial for an innovative start-up. We believe that the only validated and acknowledged proofs of **UIPC** (Utility, Innovation, Profitability and Concept) (see Table 6) [21-23] are not sufficient in the context of innovative start-ups scaling their businesses in a more and more multi-stakeholder environment.

Today, if an innovation fulfill satisfactorily the UIPC indicators, but the key partners such as customers, investors and buyers are not well informed of the relevance of this innovation, the risk of failure on the market becomes higher. Therefore, without networking and communication an innovative solution will end-up overtaken by its potential competitors.

OECD (Organization for Economic Cooperation and Development) defines the term "networking" in the context of innovation for small and medium business as a concept, which "refers to the systematic establishment and use (management) of internal and external links (communication, interaction, and co- ordination) between people, teams or organizations ("nodes or, experts") in order to improve performance" [24].

Here, we add a fifth indicator to the validated UIPC indicators in order to stress the start-ups needs in terms of acquiring knowledge about other stakeholders and their expectations.

Table 6. UIPCN Proofs.

Proof type	Definition
Proofs of **Utility (U)**	Coverage of usage and needs situations of users / stakeholders for which important needs are covered, suffering alleviated and / or malfunctions of existing systems improved
Proofs of **Innovation (I)**	Real innovation, claimable, protectable, perceived and valued by users and customers
Proofs of **Profitability (P)**	Expected profitability for the company and customers. Tendency to improve brand image, to increase the average revenue per user, to conquer new markets or to make more loyal clients (re-purchasing)
Proofs of **Concept (C)**	The conceptual solution or prototype functions effectively and efficiently in expected situations. Technological and industrial feasibility
Proof of **Networking (N)**	**Acquiring knowledge about other stakeholders and their expectations on the market and introducing company and its design solution (via communication, interaction and co-ordination) to relevant stakeholders at the right time and in the right place.**

We define thus 2 sets of indicators i.e. expected UIPCN (eUIPCN) and proven UIPCN (pUIPCN) to be compared statistically over 25 identified projects. The numerical value of each indicator varies between 0 and 1 and represents its degree of importance (0: the less important, 1: the most important). This value is retrieved from face-to-face or teleconference interviews with innovative cleantech start-ups. Each value is therefore registered in the database according to entrepreneurs' declaratives.

A first comparison between the 2 types of indicators illustrated that 6 possible comparison scenarios can be identified (see Table 7).

Table 7. Expected and proven UIPCN.

Expected Utility (eU)	Proven Utility (pU)	Comparison scenarios
e.g. 0.5	**0.5**	Expectations are met **as expected**
0.5	**0.75**	Expectations are met **more than expected**
0.5	**0.25**	Expectations are met **partially**
0.5	**0**	Expectations are **not met at all**
0	**0**	**No result as expected**
0	**0.25**	**Unexpected results**

Subsequently statistical tests (Student test) are done over each expected and proven indicator for the whole 25 observations. The results of statistical tests on UIPCN indicators are illustrated in Table 8. For a 95% confidence interval, the most significant *p-value* is the one calculated for the proof of Networking.

Table 8. Statistical *p-values* from the comparison of eUIPCN and pUIPCN

Proof type	Proof of Utility (U)	Proof of Innovation (I)	Proof of Profitability (P)	Proof of Concept (C)	Proof of Networking (N)
Statistical p-value	3,6169E-01	2,7794E-02	2,2595E-02	4,4420E-02	1,9028E-02

These statistical results show that, cleantech start-ups, in general, resort to *in vivo in situ* experimentation as a way for weaving networking links with public and private stakeholders rather than an opportunity to test and validate their solution's technical and usage performance. As mentioned before, another important purpose of companies by performing *in vivo in situ* experimentations with or in the City of Paris is to find their first customers or their marketing model. As we can see in Table 8, the proof of profitability is the most related proof to the marketing model and its value is the second most significant *p-value*.

The proof of utility is not significant at the threshold limit at 5%. The latter can be explained by the lack of relevant usage methodologies to deal with evaluating the usage situations and quantifying the ability of a given design solution to cover the expected usage situations. In [25], we have outlined the lack of usage methodologies and proposed a new usage coverage methodology.

In the following sub-section, it is worth studying learning from experimentation from a design process' perspective.

6.4. Learning from experimentation: influence on design of innovative solutions

We identify 3 design indicators in this study. The value of design indicators is declared between 0 and 1 by innovative cleantech start-ups at the end and in the middle of their experimentations. If the value of this parameter is equal to zero then we conclude that there was any influence on the design of innovative solution.

The first design indicator (**d_1**) deals with the degree of importance of prototype improvement (e.g. software updates), mainly performed during the experiments and ***Δ****MML* remains equal to 0.

The second design indicator (**d_2**) enables to calculate the importance of MML improvement (i.e. ***Δ****MML* > 0), mainly at the end of experiments.

The third indicator (**d_3**) allows measuring the importance of innovative idea generation.

Statistical tests between the above-mentioned design indicators (**d_1**, **d_2** and **d_3**) and the expected proof of concept (eC) are performed. The results of these comparisons following a Student test are the following:

- **eC** (expected proof of Concept) and **d_1** (prototype improvement with ***Δ****MML* = 0): **significant**;
- **eC** and **d_2** (MML improvement with ***Δ****MML* > 0): **the most significant *p-value*** of the 3 comparisons;
- **eC** and **d_3** (innovative idea generation): **significant**.

The results of these comparisons show that, in general for the 25 analyzed projects, the most important influence on the design of an innovation solution is the improvement of the marketing level of the solution at the end of experiments.

6.5. Analyzing the reasons of dissatisfaction of stakeholders and low efficiency of experimentation projects

In the following, we attempt to identify the ways to improve the efficiency of the existing projects regarding the context of experimentations and for the innovative cleantech start-ups. Therefore, a qualitative cause/effect model is established to identify the reasons of dissatisfaction of stakeholders and the low efficiency of some experimentation projects. In other words, the "weak signals" referring to emerging issues and unexpected results must be identified.

These analyses are done by reviewing the experimentation projects' reports and also by interviewing start-ups. Once the reasons of dissatisfactions and dysfunctions are identified, a brainstorming with experimentation experts is performed in order to find the connections between different causes. Figure 7 illustrates the results of the qualitative analyses.

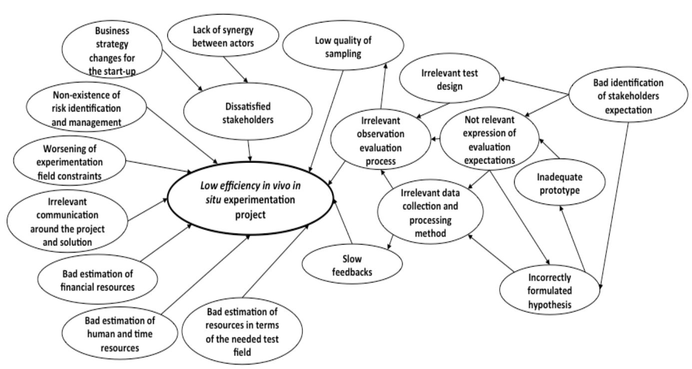


Figure 7. Cause/effect model for the identification of low efficiency of *in vivo in situ* experimentations for innovative start-ups (higher resolution version in Annex B).

The most important issues raised in these analyses represent indeed weak signals that must hint us about the probability of existence of further low efficiency experimentations:

Mismatch between the short term development processes of start-ups and the more extended processing periods for public stakeholders in organizing and issuing experimentation authorizations for start-ups;

Low speed of capturing learning and of communicating the generated knowledge inside and outside the start-up;

Irrelevancy or even non-existence of observation and evaluation methods, mainly for observing and evaluating usage situations and users' feedbacks;

Inadequacy of the prototype to experimentation context.

We then cross the identified issues with the proposed experimentation general protocol depicted in Figure 3. The surrounded objects in Figure 8 illustrate the parts of the general process for which possible ways of improvement of experimentations must be identified.

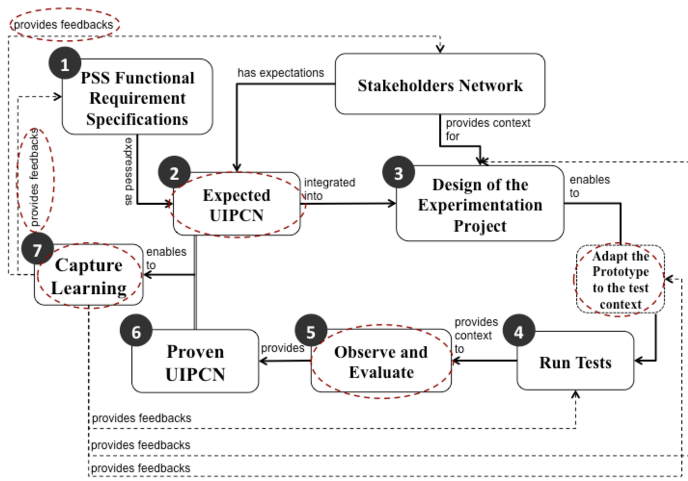


Figure 8. Identification the ways of improving the *in vivo in situ* experimentations.

In the following sub-section, we detail our proposition of recommendations aiming to improve the efficiency of *in vivo in situ* experimentation projects.

6.6. Proposition of recommendations to improve the efficiency of experimentation projects

We believe that the major issue causing low efficiency of the experimentation projects relies on early stages of the design process. Therefore, the main question here to be asked is how to integrate users' and usage situations into the experimentation of innovative product and services in early phases?

Proposed recommendations are thus based on the following grounds:

1. The users and usage scenarios should be integrated in an early maturity level: experiments over usage situations and users' feedbacks should be initiated in the problem setting phase rather than in the problem-solving phase.
2. The solutions' specifications should be clearly integrated into the definition of the expected UIPCN: early identification of experimentations' objectives to better understand where and with whom experiments should be carried on;
3. The experimentation global objectives should be expressed in terms of the expectations of all of the involved stakeholders in early stages of the project: setting up joint meetings between public and private stakeholders by using a common language (e.g. a reading grid based on UIPCN indicators) can help to point out these objectives in a more efficient manner;

4. Relevant observation and evaluation methods must be identified in early stages of experimentation and according to the experimentation objectives. For instance, eco-design and eco-innovation methods and tools can be used in order to analyze the environmental, economic and also social impacts of cleantech design solutions through experimentations.

7. Discussions and conclusions

Regarding the identified research hypotheses, presented in Section 3, the first research hypothesis (i.e. start-ups' networking objective) is accepted given the importance of the proof of Networking. The second research hypothesis (i.e. matching between expectations and results) is accepted, since there is an important mismatch between expected and proven proof of Utility. The third research hypothesis (i.e. experimentation's influence on design) is also accepted given the significance of identified design indicators. The identification of the weak signals in terms of exploring usage situations through *in vivo in situ* experimentations can be considered as a source of innovation for start-ups. For instance, observing usages will contribute to provide useful insights to make the solution more attractive in terms of its visual impact and thus creating a better "wow effect" for users. These observations and evaluations can provide innovative ideas for non-covered or poorly covered usage situations.

Two important limits of this current research must be raised: for the time being the number of analyzed companies is not more than 25 start-ups, which is a low statistical sample. Besides, there is a lack of reliable data over the identified indicators. Therefore, a time-consuming process of interviewing start-ups has been conducted.

In this paper, the case of cleantech innovative start-ups was analyzed as an important case study, since cities invest important public funds in this field, and support cleantech innovative design solutions. In France and mainly in Paris there are important sustainability challenges [3]. According to the Global Cleantech Innovation Index 2014 [26], which investigates the global state of cleantech innovations in entrepreneurial start-up companies, the score of France in terms of emerging cleantech innovation indicator remains relatively high thanks to important venture capital investment and environmental patents. Therefore, endorsing the start-ups businesses in a local scale deserves particular attention. In this regard, we believe that the development of methodological tools for experimentation can help start-ups to better measure and validate the quality and the significance of their businesses.

The proposed methodology can also be applied to other types of *in vivo in situ* experimentation projects, such as in the case of smart street furniture. However, data over these projects and the feedbacks of companies must be systematically collected and sorted in order to make analysis more accurate.

Nowadays, the City of Paris encounters new challenges regarding the *in vivo in situ* experimentation of innovative solutions: How to verify the effective matching between the tested product-service-system and users' expectations through experiments? How to collect the maximal useful feedbacks of experimentations in order that the whole society (companies, public services...) provides the right offer at the right time to the right market? Therefore, answering the question of experimentation's performance improvement arouse interest of start-up companies to better target their market and also enhance the decision making process of innovative solutions' public buyers.

The City of Paris will organize during the United-Nation's event on climate change, called COP21 in November and December 2015, a demonstrator (or, a showroom) of innovative solutions for the climate and the energy transition on Paris public spaces. This showroom can play an important role in emphasizing the importance of proof of Networking.

Nevertheless, if it appears clearly that cleantech innovative start-ups need to test and validate the performance of their design solutions, the research on experimentation should also concentrate on improving other UIPC proofs mainly in early design stages.

Acknowledgements

The authors gratefully acknowledge the meaningful helps of Paris&Co Expérimentation team, mainly Sabine Romon and Arthur Coussy. We also acknowledge the clean technology incubator of Paris as well as the 25 start-ups who kindly responded to our questions.

References

[1] EarthInstitute, 2005, "The Growing Urbanization of the World," http://www.earthinstitute.columbia.edu/news/2005/story03-07-05.html.

[2] UN, 2007, "Climate Change," UN Commission on Sustainable Development, https://sustainabledevelopment.un.org/content/documents/habitat_2may_cc.pdf.

[3] City of Paris, 2004, "Paris Climate Protection Plan: Plan to combat global warming," CityofParis, Paris.

[4] Canadian Clean Technology Industry, 2013, "The 2013 Canadian Clean Technology Industry Report," Canada, http://analytica-advisors.com/sitefs/default/files/CCTIR_2013 Prospectus.pdf.

[5] Paris&Co, 2015, "Paris and Co Cleantech Incubator," http://incubateurs.parisandco.com/programme/42.

[6] eGreen, 2014, "eGreen building's energy efficiency," http://www.egreen.fr/.

[7] Eurisy, 2014, "CitéGreen engages citizens to play and reduce their carbon footprint," http://www.eurisy.org/good-practice-cit%C3%A9green-engages-citizens-to-play-and-reduce-their-carbon-footpr_94.

[8] Paris&Co, 2014, "Paris&Co Experimentation," http://parisandco.com/page/experiment/our-mission.

[9] von Hippel, E., 2005, Democratizing Innovation, MIT Press.

[10] Schrage, M., 2000, Serious play: How the world's best companies simulate to innovate, Harvard Business Press.

[11] Thomke, S. H., 1998, "Managing experimentation in the design of new products," Management Science, 44(6), pp. 743-762.

[12] Thomke, S., von Hippel, E., and Franke, R., 1998, "Modes of Experimentation: An Innovation Process - and Competitive - Variable," Research Policy, pp. 315–332.

[13] Montgomery, D. C., 1984, Design and Analysis of Experiments, John Wiley & Sons, Inc.

[14] Thomke, S., 2003, Experimentation Matters, Harvard Business School Publishing Corporation.

[15] Belis-Bergouignan, M.-C., Oltra, V., and Saint Jean, M., 2004, "Trajectories towards clean technology: example of volatile organic compound emission reductions," Ecological Economics, 24, pp. 201–220.

[16] Telenko, C., and Seepersad, C., 2014, "Scoping usage contexts and scenarios in eco-design," Proc. ASME 2014 IDETC/CIE.

[17] Sonderegger, A., 2010, "Influencing Factors in Usability Tests, The testing Situation, the Product Prototype, and the Test User," PhD Thesis, University of Freiburg, Freiburg.

[18] Farel, R., and Bekhradi, A., 2014, "Energy efficiency of industrial systems: a design research perspective," Proc. Proc. ASME 2014 IDETC/CIE.

[19] Tao., L., Probert, D., and Phaal, R., 2008, "The concept of 'Innovation Readiness Levels'– a new approach for managing the process of innovation. Emerging and new approaches to R&D management R&D," Management ConferenceOttawa.

[20] Otto, K., and Wood, K., 2001, Product Design: Techniques in Reverse Engineering and New Product Development, Prentice Hall, University of Michigan.

[21] Yannou, B., Farel, R., and Cluzel, F., 2015, "The DSM value bucket tool," ICoRD'15, International Conference on Research into Design Banglore, India.

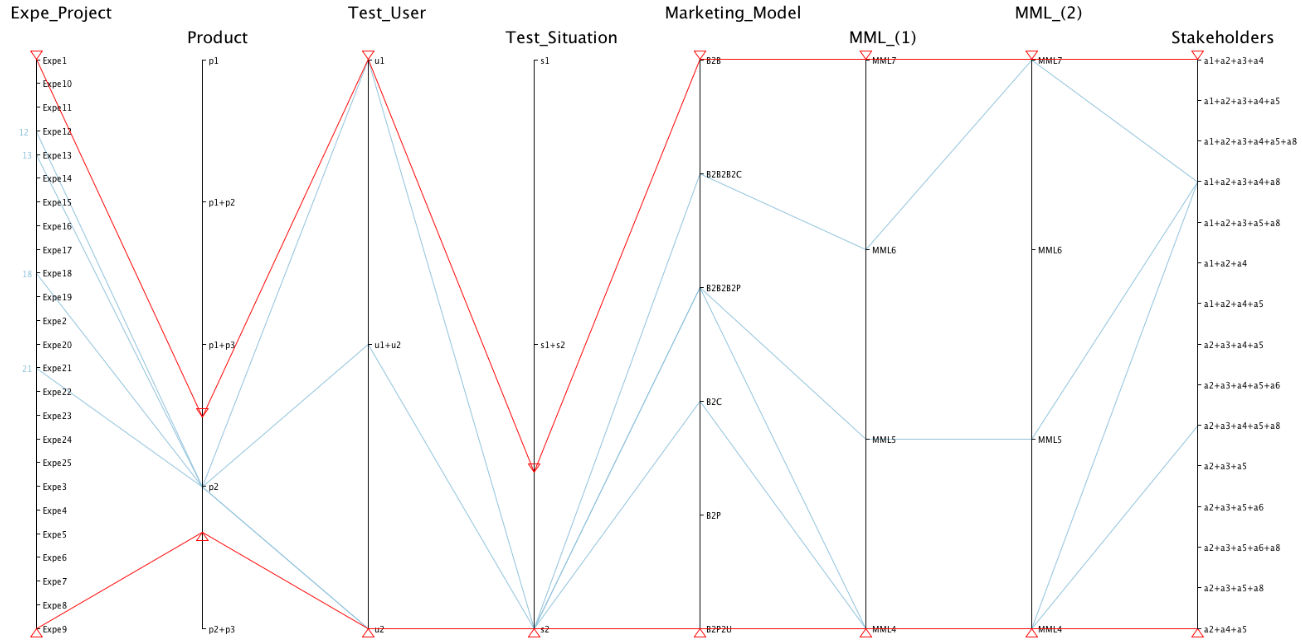
[22] Zimmer, B., Yannou, B., and Stal–Le Cardinal, J., 2012, "Proposal of a radical innovation project selection model based on proofs of value, innovation, and concept," International Design Conference - Dubrovnik - Croatia, pp. 141-150.

[23] Yannou, B., Jankovic, M., and Leroy, Y., 2011, "Empirical verifications of some Radical Innovation Design principles onto the quality of innovative designs," in ICED 2011, Copenhagen, Denmark.

[24] van Aalst, H.-F., 2003, "Networks of Innovation: Towards New Models for Managing Schools and Systems," OECD.
[25] Bekhradi, A., Yannou, B., Farel, R., Zimmer, B., and Chandra, J., 2015, "Usefulness Simulation of Design Concepts," Journal of Mechanical Design.
[26] Cleantech Groupe and WWF, 2014, "Global Cleantech Innovation Index 2014," http://info.cleantech.com/CleantechIndex2014.html.

APPENDIX

Annex A



Annex B