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Development of a decision support model to assess technological paradigms in the surfacing industry

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Introduction

One of the fundamental concepts that should be kept in mind when dealing with innovation and product development is that different kinds of innovations must be managed in their own specific ways.

For example, as it has been proven, customer-driven approaches and traditional market research are usually quite successful when it comes to incremental innovations. The picture radically changes, though, when companies have to deal with radical innovations, that imply changes in both the underlying technology and the product architecture.

Firms that aim to introduce radical innovations have to face several issues during all product lifecycle, which is particularly problematic because of both technological and market risks: in fact, when the design process starts, there are a lot of uncertainties difficult to manage, such as the actual performances of the new technology, which are always difficult to predict, and the customer value: the latter is strongly influenced by cultural aspects, such as the "meanings" that customers attach to a product, which are typically latent and tacit.

For all these reasons, given the general unpredictability that characterizes the context, it's difficult to adopt a systematic approach when dealing with radical innovations: therefore, the possibility of developing effective tools to support the managing of radical innovations is a debated issue among researchers, that in recent years have been focusing their efforts towards the development of methods to anticipate and predict the emerging of new technological paradigms.

Among the various contributions that deserve to be cited, we can find the "Blue Ocean Strategies", discussed by Kim and Mauborgn, which focus on the opportunities that innovative firms have to create non-existing markets.

In the Engineering Design field, important contributions were brought by Altshuller with "Laws of Engineering System Evolution", that aims to identify repeatable patterns in artefacts evolution.

More recently, in 2013, Borgianni et al. proposed a tool to estimate the probability of success of a new artefact, through an analysis of its functionalities and features with respect to the alternatives existing in the market, developing metrics to forecast the expected market appraisal. The work has been based on a database of past successful innovations and market failures, which have been used to build the metric applying a logistic regression.

In 2017, Casagrande et al. provided an increased robustness of the database and expanded the results to get a tool which benefits both managers and designers.

Each case study was analyzed categorizing product features in *useful functions*, *harmful functions* and *resources*, and distinguishing the modifications that affected product features in four different typologies – *create*, *raise*, *reduce* and *eliminate*. The independent variables of the model were the number of occurrences of each pairwise relationship (i.e. create a useful function, raise a harmful function etc...) and the dependent one was a dichotomous variable representing a success product if it was equal to 1 or a market failure if it was equal to 0.

This thesis is a first attempt to enhance the contribution made by Casagrande et Al., starting from the idea that building a generic model for products belonging to different markets can be effective, but is has some intrinsic limits, since it will not provide a full explanation of design actions and their impact on the final product. Every market has its own dynamics and, as a consequence, design choices and actions may not have the same impact for products belonging to different markets. Hence, the ideal way to provide a systematic approach to the managing process of radical innovations would be to develop different predictive models for markets that have different needs.

Therefore, the purpose of this thesis is to apply the same framework followed by Borgianni and Casagrande to a new database, started from scratch, that collects products belonging to the same market in order to develop an *industry-specific* decision support model to assess *technological paradigms*. The market that has been chosen to develop the model is the *surfacing industry*, which has several fields of applications (i.e, decorative laminates, flooring etc...). The products that have been individuated belong to several families of materials, like plastic laminates, artificial stone, porcelain grès, engineered wood, smart glass and so on.

The first chapter of the thesis discusses innovation in general and then dwells more specifically on the issues and the problems typical of radical innovation; the second chapter analyses previous tools and methods to anticipate technological paradigms, presenting their strength and their limits; the third chapter discusses the dynamics of the surfacing industry, in order to provide an overview of the research field; the fourth chapter presents the methodological approach used to build the model, while the fifth chapter discusses the results, the limits and the issues observed.

Chapter 1: An overview of innovation and related issues

1.1 A few definitions of innovation

Defining *innovation* is not an easy task, since the word often gets misunderstood or confused with other related terms, such as "invention", "discovery" or "*product development*". Despite its meaning being different, innovation is still closely linked to all these concepts, therefore analyzing them in the first place can be a good starting point to really grasp the idea behind innovation itself.

A "discovery" can be defined as the act of uncovering something previously unknown, and it can be framed inside the context of the discipline that we all call "science", which generates new knowledge by investigating on natural and social phenomena with strict and rigorous methodical procedures.

An "invention" is the act of devising a solution to a problem and it's the outcome of the activity called "technology", which aims to ideate and validate artifacts by conjugating scientific and empirical knowledge.

Finally, according to Roberts' definition (1987), innovation can be defined as the "economic exploitation of an invention": in other words, a "shift" from invention to innovation is being acted upon when an invention is brought to the market giving customers a certain utility that is greater than the cost of production.

One can might wonder how the last mentioned step of turning an invention into a product, that can be useful to society in the everyday life, actually happens. As a matter of fact, a whole business process revolves around this phase and it's known by the name of "product development": in comparison to other business processes, product development presents several peculiarities and raises significant managerial challenges, being highly interfunctional, interdisciplinary and knowledge-intensive as well.

The attempt of defining innovation captivated many other experts too, who tried to define the concept shaping it on the basis of their perception and their experience in the field. For instance, Nick Skillicorn, chief editor of Idea to Value and also CEO & Founder of

Improvides Innovation Consulting, defines innovation as the act of “turning an idea into a solution that adds value from a customer’s perspective”. When asked about the mistakes that companies often do when talking about innovation, he says that “they talk about it being a company value without actually putting the required level of support behind it to make it happen”. Coming up with ideas can be relatively easy, fast and cheap, but then those ideas need to be executed: this is where companies often fail, by not providing the required level of time and budget to take a rough idea, refine it, experiment on it and finally turn it into a real solution. In more technical words, a process so critical like product development is somehow often underestimated by firms that are trying to innovate, falling into the trap of believing that the gap between the concept idea and the actual final development is not that wide when in fact it is.

Some other interesting ideas were pointed out by Pete Foley, CEO of Open Data Group, who defines innovation as “a great idea, executed brilliantly, and communicated in a way that is both intuitive and fully celebrates the magic of the initial concept. All these parts are needed to succeed”. What is interesting about this interpretation of innovation is that the focus in this case is on giving justice to the initial concept. When innovating, you’re attempting to translate into reality an idea that is possibly perfect but only in abstract terms, so it becomes clear that no mistake is allowed - both from a technical and a strategic point of view - if you want to succeed.

1.2 Determinants of innovation: demand pull and technology push

One of the most lively debate in the field of innovation concerns its causes or, better said, its determinants.

As it often happens, the different approaches that have been adopted tended to be in contrast, marking two different paths and dividing the experts in advocates of one or the other.

More specifically, the *technology push* approach states that innovation can be seen as independent from market demand and occurs as a consequence of technological development, which drives the whole process and finally matches a latent demand.

On the other hand, the *demand pull* approach affirms that the process starts by observing the demand of improvements from the market and then channel the technological efforts into the satisfaction of the emerging needs.

The field of technology studies started discussing this issue in the 1970s and, after years of investigating the two possibilities with a "mutually exclusive" approach, finally realized that, actually, both of them were important for innovation and for the development of technologies in general (Dosi, 1982; Mowery and Rosenberg, 1979): as a consequence, experts came to the conclusion that technological innovation can be due to either of the two determinants, depending on the stage and type of innovation. In fact, the innovation process is characterized by the alternating stages *evolutionary* and *revolutionary progress* (Tushman and O'Reilly 1997; Iansiti 2000), in which firms should follow different approaches. The importance of distinguishing these alternating stages becomes more evident after acknowledging that, most of the times, by picking an industry and identifying a relevant performance indicator for its products, the evolution of this indicator will not proceed in a straight line.

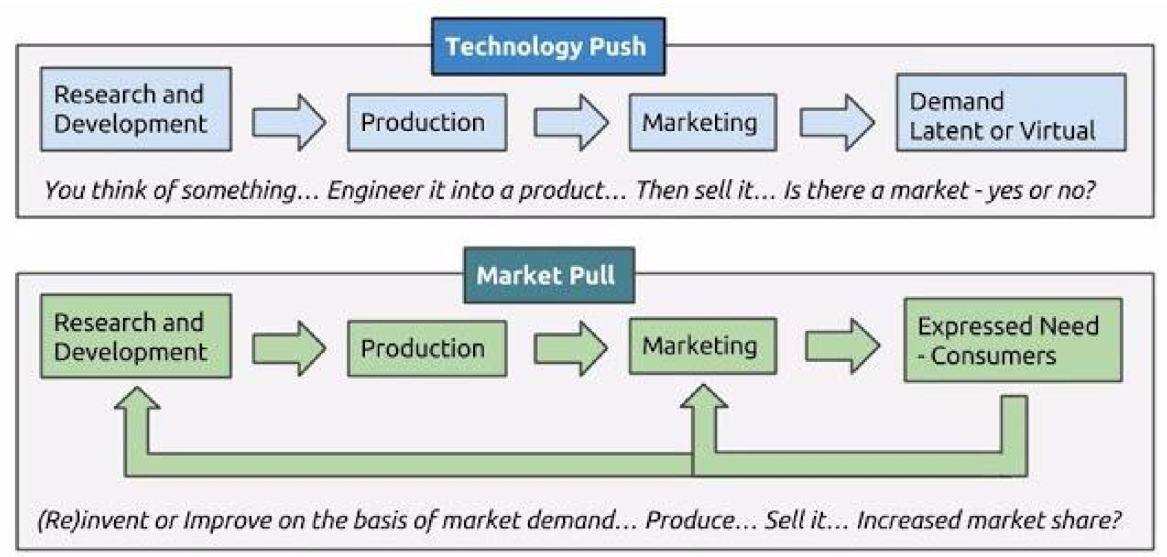


Figure 1 – Technology Push/Market Pull

1.3 S-curves and technological paradigms

As anticipated, the evolution of the technological process typically is not linear; instead, it follows a sequence of *s-curves*. The s-curve innovation thinking is attributed to Richard Foster (1986) and made famous by Clayton Christensen in the book "Innovator's Dilemma," where he discusses how each successive computer hard drive industry got wiped out.

Observing said curves, it’s possible to notice how the emergence of a new technology is a process that requires the reaching of a certain grade of maturity: until then, the performance of the technology won’t take off. Once reached this point, the performances grow very quickly until a limit, which is intrinsic to the technology itself, is reached and determines a saturation point.

Based on this, the evolutionary progress corresponds to the process of moving along a s-curves, while the revolutionary progress occurs in the transition from a s-curve to the following one.

The s-curve pattern of innovation highlights the fact that as an industry, product, or business model evolves over time, the profits generated by it gradually rise until the maturity stage. As a product approaches its maturity stage, a business should ensure that it has new offerings in place to capture future profit opportunities.

Thinking about what generally happens in each industry, it can be noticed that often firms ignore the march of technology, being reluctant to get started on the next technology and abandon the current technology. This reluctance is mostly due to the fact that, at the early stages, each new s-curve looks unattractive from the existing s-curve’s point of view.

The s-curves are to be framed within a greater context than the technological process per se, and this context can be identified in a broader concept that has been defined “technological paradigm”, term first introduced in 1982 by Giovanni Dosi, who borrowed it from Thomas Kuhn’s concept of “scientific paradigm”, which can be described as a fundamental change in the basic concepts and experimental practices of a scientific discipline. Kuhn contrasts paradigm shifts, which characterize a scientific revolution, to the activity of normal science, which he describes as scientific work done within a prevailing framework or paradigm.

The technological paradigm results from a series of elements: methods, tools, business models from the *supply-side* and beliefs, needs, rules from the *demand-side*: all these elements together form a coherent set able to generate a *technological trajectory*, which has to be technically feasible but at the same time well received by the market. In other words, the logic behind technological paradigms and their emergence lies in the innovative content of a new technology and its ability to meet customer needs as well. All these elements are necessary to the diffusion of a new paradigm, therefore an innovative technology that works in technical terms but doesn't match the customer needs is not sufficient to allow the emergence of a new paradigm.

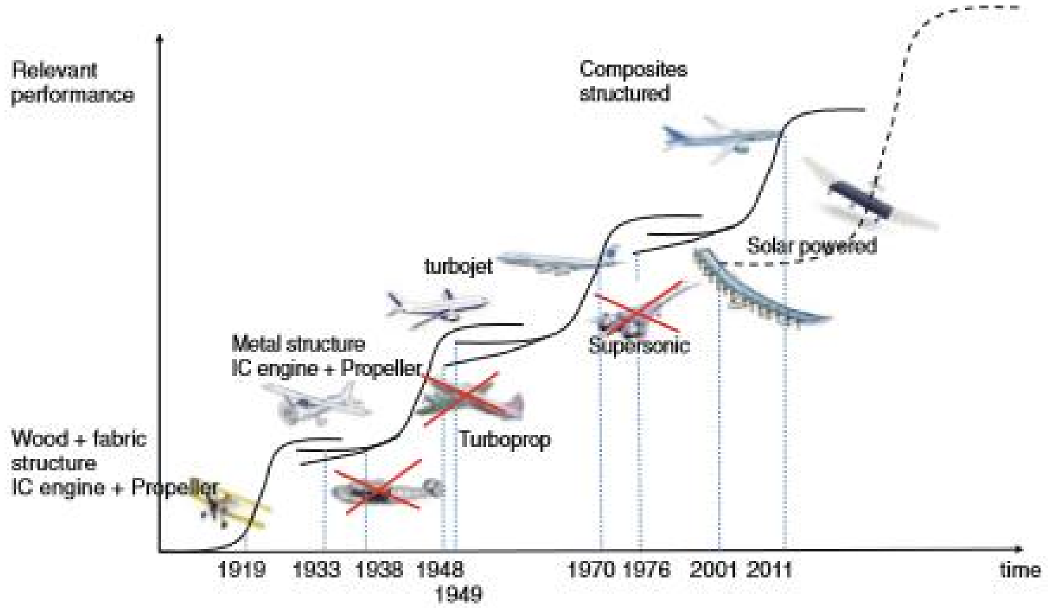


Figure 2 – S-curves

1.4 How innovations can be classified

About the classification of innovation, the first thing to be said is that there's not a unique, strict categorization in the literature. That is clearly due to the intrinsic nature of innovation, which is a very wide concept which can be studied from multiple perspectives that highlight different peculiarities in the analysis.

So, depending on the "subject of study", there can be found several kinds of taxonomies, being proposed with different purposes from different authors in various contexts and periods of time, which are all summarized, classified and explained in the table below.

Subject of study	Classification	Meaning
Technical features of the product	Incremental vs radical	Alter vs not alter technical trade-offs of the product
Knowledge required to the development	Competence enhancing vs competence destroying	strengthen vs. devaluate the current competencies of firms
Functionality being affected	Core vs peripheral	Affect a core functionality of the product vs an ancillary one.
Impact on the industry	Sustaining vs disruptive	Not lead vs lead to substantial changes in current competitors' position
Scope of the innovation	Product vs process	On the product vs on the manufacturing process

Table 1 – Classification of innovations

Apart from the typologies mentioned above, there's another classification which is very popular and deserves a separate discussion: this taxonomy looks at two significant subjects at the same time and analyzes the relationship between them proposing a classification in four different kinds of innovation. Product architecture is analyzed on one side, and the underlying technology on the other side. Based on the idea that an innovation can either change or leave unchanged the product architecture and the underlying technology, there are four different cases, all listed below:

- *Incremental innovation* affects neither the product architecture nor the underlying technology and therefore it's relatively easy to manage, since firms can usually replicate the experience gained with previous products;
- *Modular innovation* doesn't change the product architecture but changes the underlying technology in one or more functional elements: this could result in a change of the competencies required, but usually in a way that's limited to the affected modules, therefore the development of the complete product itsefl will still be pretty easy to manage anyway.

- *Architectural innovation* is characterized by changes in the relationship between components but not in the underlying technology: it's generally not very easy to manage, and the reason is due to the fact that modifying the product architectures also requires developing new organizational routines, and this implies some costs due to the need of following a "*trial and error*" approach.
- *Radical innovation* is the most difficult to pursue, since it implies changes in both the underlying technology and the product architecture. One of the most common problems when dealing with this kind of innovation is that, knowing the consequences of an architectural changes, firms often tend to treat a radical innovation as a modular one, by changing only product subsystems and avoiding to alter the mutual relationship between components.

1.5 The disruptive nature of radical innovation

One of the most striking aspects of radical innovation is its *disruptive* nature, that potentially can displace established market-leading firms, products, and alliances. The term "disruptive" was defined and first analyzed by the American scholar Clayton M. Christensen and his collaborators in 1995, and has been called the most influential business idea of the early 21st century.

Disruptive innovations tend to be produced by outsiders and entrepreneurs in startups, rather than existing market-leading companies. The business environment of market leaders does not allow incumbents to pursue disruptive innovations when they first arise, because they are not profitable enough at first and their development can take scarce resources away from sustaining innovations (which are needed to compete against current competition). A disruptive process can take longer to develop than by the conventional approach and the risk associated to it is higher than the other more incremental or evolutionary forms of innovations, but it's also potentially able to achieve a much faster penetration and higher degree of impact on the established markets.

While studying the "disruptiveness" of radical innovation, scholars pointed out three main reasons for this phenomenon:

- *Inability of incumbents to join the emerging paradigm*: this is due to the technological distance but also to more subjective factors like inertia in understanding the new situation (*cognitive inertia*) or in reacting effectively to it (*action inertia*). It often happens that, when analyzing the sources of competitive advantage, incumbents erroneously tend to look at strategies which granted them success in the past, but that could result in a total failure when dealing with emerging paradigms. Other reasons why incumbents decide not to follow new paradigms are the *sunk costs* associated to previous investments and the attitude of observing the *status quo* and not thinking ahead.
- *Tendency of incumbents to neglect emerging markets:* in more technical words, authors call this the *Christensen effect* (Christensen 1997). Since incumbents are often influenced by the needs of their current customers, when a new technology emerges they tend to delay its introduction, because the initial performance of the new technology is inferior to the one achieved by the established. Sometimes it happens, though, that the inferior performance of the new technology is actually completely satisfactory for a new market overlooked by incumbents.
- *Different goals of incumbents in comparison with new entrants:* Incumbents and new entrants have different objective functions because incumbents are usually concerned with profitability of the business as a whole, while new entrants try to maximize the probability of survival (Swinney et al., 2011), and the *dissimilarity of goals* has obviously an influence on the different timing of entry.

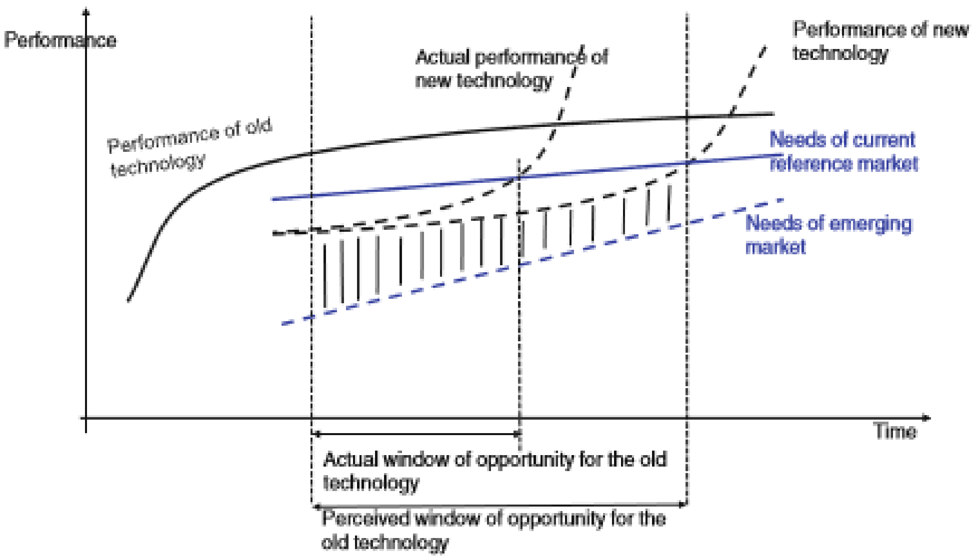


Figure 3 – Christensen Effect

1.6 When radical innovation doesn't disrupt

There are situations in which radical innovation ends up not being disruptive, because the right conditions were not present. There can be many different reasons why radical innovation sometimes doesn't disrupt; the main ones are listed and described below:

- *Markets for technology*: sometimes the new entrant and the incumbent end up finding a deal. For example, the incumbent may buy a license for using a new technology or directly acquires the entrant company: the latter case is a common destiny for startups, especially when they're backed up by venture capital firms.
- *Misleading s-curves*: when analyzing s-curves, it's important to keep in mind that they are not usually "smooth" curves, but they appear to be more like an ensemble of little *nested s-curves*, which represent the so-called *product generations*. Therefore it's not always easy to establish whether a saturation point is relative to a product generation or to a *technological limit* intrinsic to the paradigm. It's also important to keep in count that there are cases in which the benefits of the new technology create a sort of *spillover effect*, which facilitates improvements also for the old technology and paradoxically gives an advantage to incumbents. From a technical point of view, this determines on the s-curves the so-called *sailing ship effect,* in which the old technology becomes able to maintain its lead for more time thanks to the spillover and to the incumbents retreating to segments where they currently have more competitive advantage. If the sailing ship effect lasts enough time, the development of the new technology can stop completely because of the discouragement and the adverse conditions.

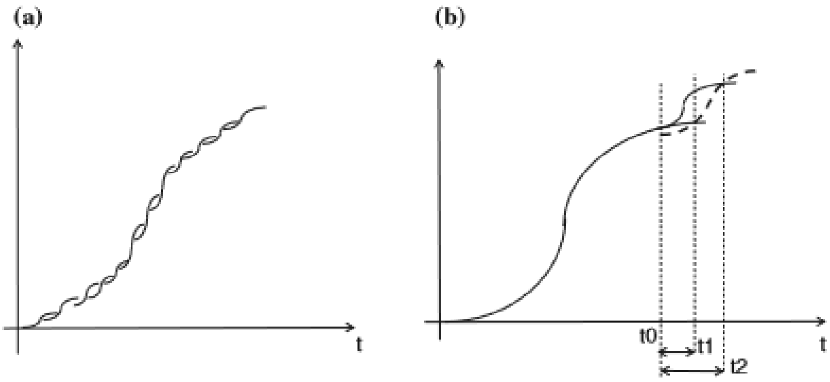


Figure 4 – Sailing ship effect

- *Localized technological change*: this term was introduced for the first time by Antonelli in its theory in 1995. The idea behind this is that, when having to choose between the old and the new technology, customers take into consideration *switching costs* and decide to adopt the new technology only when the utility associated to it is greater than the costs of abandoning the old one.
- *Appropriability regimes and complementary assets*: appropriability refers to the capability of the proponents to keep the economic value generated to themselves. Complementary assets can be defined as the infrastructure that is necessary to produce a product or a service.

1.7 Customer-driven and design-driven approaches

When firms are looking to deliver innovations to the market, there are different approaches they can follow. The so-called *customer-driven approaches* focus on customer needs and their satisfaction as a first starting point to come up with new innovative products. These kinds of approaches are usually successful when it comes to incremental innovation, but can turn out as a failure when dealing with radical innovations: in fact, radical innovations are usually technology push, they often have as the main target markets that don't even exist yet and they satisfy needs that are latent and tacit. In these cases, customer-driven approaches don't make sense, because customers wouldn't be able to express and articulate their own needs.

In a somehow opposite way to the customer-driven approach*, design-driven innovations* focus on tacit cultural and aesthetic aspects which play indeed a very relevant and influential role, especially when it comes to products that can be considered some sort of *status symbols*.

Chapter 2: Tools to anticipate the success of new artefacts

2.1 TRIZ – Theory of Inventive Problem Solving

TRIZ (literally "theory of the resolution of invention-related tasks") is "a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature"; it was developed by the Soviet inventor Genrich Altshuller (1926-1998), beginning in 1946, while he was working for the technical corps of the Soviet Navy. He was jailed for political reasons and kept working on its theory while he was interned in a labor camp, analyzing an enormous amount of inventions – around 40000 patents – in order to identify *patterns in systems evolution* and induce general rules.
The theory developed by Altshuller gained a lot of attention in the following decades, attracting many researchers: in 1971 the first TRIZ teaching facility, called the Azerbaijan Public Institute for Inventive Creation, was established in Baku. Later on, the number of patents analyzed grew to about 1 million, thanks to the contribution of all TRIZ community.
One of the first fundamental concepts in TRIZ theory is the idea that any *technical system* (TS) delivering a *function* is formed by the following elements:

- A *Tool*, which is the working element that delivers the function;
- An *Engine*, which provides the energy required by the tool;
- A *Transmission*, allowing the flow of energy from the engine to the tool:
- A *Control*, which governs one or more of the previous elements.

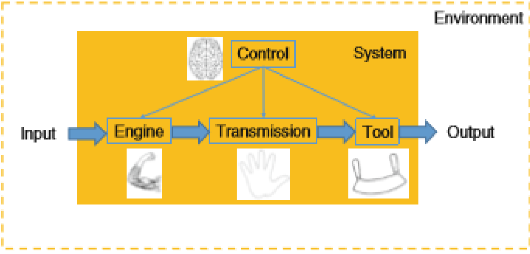


Figure 5 – TRIZ Technical System

According to what Altshuller called the *law of evolution*, one peculiarity of technical systems is that they evolve in time, in a way that makes possible the substitution of human activity with artificial means. What allows this evolution is the solving of the so-called *contradictions*: contradictions can be defined as conflicts between a system and its environment, or between the components of the system itself. The concept of contradiction can be better explained through three elements and their mutual relationship: one *control variable* that can be modified by the designer and two *evaluation parameters*. The contradiction emerges when, changing the control variable, there is a *positive effect* on one evaluation parameter and a *negative effect* on the other one.

Analyzing contradictions on his large inventions sample, Altshuller noticed that they usually emerge on a relatively limited number of features, and he came up with a list of 39 *contradiction instances*. Considering contradictions as asymmetrical, it can be concluded that the possible number of pairwise contradictions is 39 × (39 - 1) = 1482.

In Altshuller's mind, contradictions should be used as a guideline for the *design process* in new inventions: designer's "task", in fact, is to find a solution to a contradiction and possibly introduce an improvement.

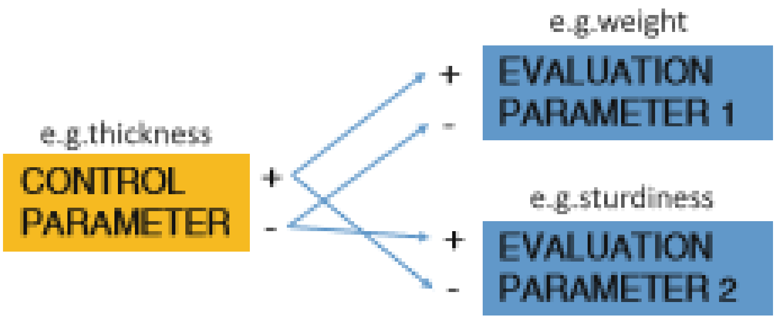


Figure 6 – TRIZ (Contradictions)

Altshuller identified three main approaches to solve contradictions:

- *Satisfying the contradiction*, which means understanding it and identify a compromise solution. In other words, the designer comes up with a *technical tradeoff* that limits the negative impact of the contradiction. This option doesn't bring any significant technical changes in the system itself and it's typical in incremental innovations;
- *Bypassing the contradiction*, which means acknowledging it and explicitly deciding not to deal with it, concentrating on the contradictions considered as more relevant for the design process.
- *Overcoming the contradiction* by identifying *technical changes* in the system that allow the *separation* of contradictory requirements. This is the most inventive solutions and it typically leads to radical innovations.

2.2 Shaping Strategies

In the innovation field, *shaping strategies* are those kinds of strategies deployed by innovative firms that are able to operate in the market with a high degree of *unpredictability* to the point of "reshaping" an industry. Shaping strategies are all about identifying an "inflection point" in the early development of new markets, as well as in the disruption of existing ones. Obviously, one firm alone will encounter many difficulties in the attempt of exerting enough influence to change the rules of a market, therefore it is fundamental for an innovative firm aiming to reshape an industry or a segment to attract and engage as many *stakeholders* as possible. Shaping strategies are usually not limited to product innovations, but they're extended to a wider scope, and they mainly refer to business models in their entirety.

About the idea that innovative firms can potentially "change the rule of the game", some important contributions have been brought by Kim and Mauborgne in their book "Blue Ocean Strategies", in which the authors suggest that innovative firms and startups have the potential to create *non-existing markets*, thanks to their *technological advantage*: most of the times the best strategy for new entrants is not to face the incumbents on territories where the latters have gained a solid competitive advantage, but instead to focus on *uncovered* and *unexplored* new markets where their new technology could perfectly meet *latent* and *tacit* needs of new customers.

Kim and Mauborgne described the existing markets as a “Red Ocean”, a sort of gigantic battlefield in which firms fight to get the biggest market share. “Blue Oceans”, instead, are defined as “an untapped market space, demand creation, and the opportunity for highly profitable growth”: therefore, in blue oceans competition is not relevant, because nobody is considering them yet as a playing territory.

An example of a Blue Ocean Strategy is represented by Cirque du Soleil, which grasped the following fundamental concept: in order to succeed, companies have to stop competing one with the other and the only way to beat the competition is to stop trying to beat the competition.

Cirque du Soleil was the first to introduce the concept of “multiple productions”, offering the best of circus and theater eliminating unsuccessful forms of entertainment and giving people a reason to go to the circus more frequently. The result was the creation of a “Blue Ocean”, because the form of entertainment that Cirque du Soleil brought to the audience was something totally new.

2.3 The Four Actions Framework

Kim and Mauborgne also suggested a *support tool* for creating competitive advantage while trying to implement a Blue Ocean strategy: the so-called “*Four Actions Framework*”.

The authors suggest that, when firms want to create a new value curve, they should be trying to answer to the following questions:

- Which of the factors that the industry takes for granted should be *eliminated*?
- Which factors should be *reduced* well below the industry’s standard?
- Which factors should be *raised* well above the industry’s standard?
- Which factors should be *created* that the industry has never offered?

By answering to the first two questions, firms can potentially drop their cost structure, while answers to the last two questions potentially allow the creation of new value that can generate a solid and sustainable competitive advantage.

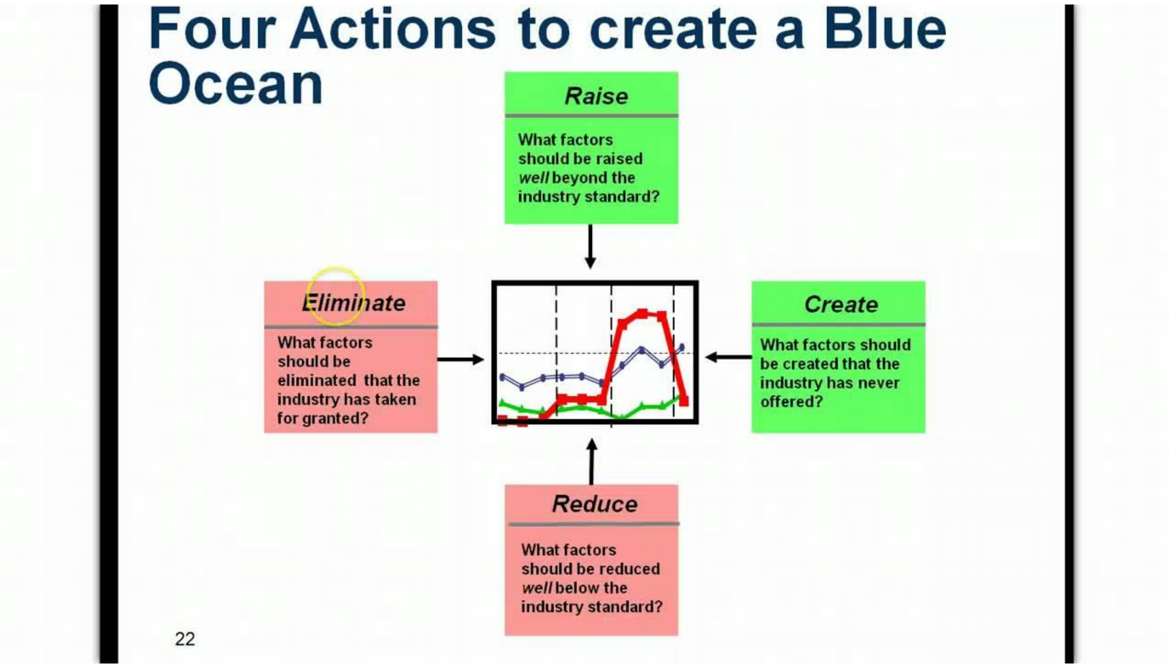


Figure 7 – The Four Actions Framework

2.4 VAMs – Value Assessment Metrics (Borgianni)

Value Assessment Metrics (VAMs) is a tool proposed by Borgianni in 2012 to "estimate the success potential of a new artefact through a balance of its functionalities and features with respect to the alternatives existing in the market". The aim of the research, that led to the development of this tool, was primarily the definition of a metric capable to provide *quantitative information* about the *probability of success* of new initiatives taken on by innovative firms. This necessity arises from the *lack of viable methodologies* supporting actors playing today in the radical innovation field and helping them identifying latent customers' and stakeholders' needs.

The following steps were followed to construct a viable model:

- *Identification of clustering criteria* allowing the classification of product features with respect to the functional role
- *Selection of case studies* divided in successful and unsuccessful stories.
- *Analysis of the collected case studies* following the clustering criteria mentioned before.
- *Identification of correlations* between value profiles and market appraisal by following two possible approaches: a statistical model obtained through a logistic regression and an empirical model exploiting artificial Neural Networks.
- *Cross-validation* of the obtained models.

2.5 Support tool to assess technological paradigms (Casagrande)

The model which will now be described is a prosecution of Borgianni's VAMs and it consists of the same framework applied to a larger database. Firstly, the original database was cleaned up removing 21 services, because of the difference between *product development* and *service development* (Griffin et Al., 1997). The database was then expanded adding 39 products, with at least three features subject to modification. The ultimate result was a data set consisting of 110 products, equally divided between successes and failures.

Action	Feature	Functional Analysis
CREATE	Ability to mount the camera to one's body, helmet, vehicle, etc.	UF
CREATE	Resistance	HF
RAISE	Accessories availability	UF
RAISE	Cheapness	RES
RAISE	Ease of use	RES
RAISE	Portability	RES
REDUCE	Quality	UF
ELIMINATE	Controllability	UF

Figure 8 – GoPro Functional Analysis

The model correctly predicted 86% of the overall cases: more specifically, the percentage of correctly predicted success cases was 82%, while the percentage of correctly predicted failure cases was 91%.

After cross-validation, four indexes were computed in order to compare the model with Borgianni's VAMs:

- *Precision*: the chance that a predicted success is an observed success (Maroco et Al., 2011)
- *Recall*: the capability to reveal a potential success (Maroco et al., 2011)
- *F-measure*: a balance combination of precision and recall (Powers, 2011);
- *Matthews correlation coefficient*: the capability to discern unsuccessful projects (Bendtsen et al., 2004)

The index comparison shows how the new model outperformed the old one; the results are summarized below:

Index	**VAM (reg_new)**	**VAM (reg_old)**
Precision	0,90	0,79
Recall	0,82	0,83
F-measure	0,86	0,81
Matthews correlation coefficient	0,73	0,61

Figure 9 - Index Comparison

2.6 State of art and aim of the research

The outcome of Casagrande's research work indeed represents a valuable *decision support tool* for managers and designers, requiring basic ICT infrastructures and skills in product development processes.

Looking at the *significance of predictors* in the output of the model, it's possible to notice that 6 out of the 12 *independent variables* have a *p-value* less than 0.05 and therefore have a significant impact of the output:

- Create a Useful Function
- Create a Resource
- Raise a Resource
- Reduce a Useful Function
- Reduce a Resource
- Eliminate a Useful Function

A larger database would probably allow to attribute a significant impact to the remaining variables too, and this would further validate the model. The authors also explained how other variables could be added in order to describe more deeply every product: for example, it would be interesting to include in the regression equation a variable relative to the *timing of the paradigm shift* (before or after having reached the maturity), in order to include also other strategic aspects that are of course relevant to the firms.

Another limit of the model is represented by the fact that each new feature describing a new paradigm is analyzed in the time lapse with respect to their actual impact on the product use. Actually, it should be kept in mind that innovations could affect a product when using it (i.e., a car reducing noise while driving it) or even when not in use (i.e, a folding chair allowing to save space when not in use); therefore, it would be essential to extend the study also to those cases in which innovations affect products when they are not used.

However, the most evident limits of this model are probably given by its "generic" character: what is meant by this is that this model is not *industry-specific* and therefore, despite it being of course a very useful tool, it has some *intrinsic limits* that do not make it possible to provide a full explanation of design actions and their impact on the final product.

This last limit, in particular, represents the starting point for the research work presented in this thesis: the choice of starting to develop an industry-specific model is based on the idea that every market has its own dynamics. As a consequence, design choices and actions may not have the same impact for products of every market.

The idea is to develop different predictive models for industries that have different needs and, collecting more and more cases, detect and analyze the peculiarities of every sector.

Chapter 3: An overview of the research field

3.1 A brief description of the surfacing industry

The sector that has been chosen to develop a first industry-specific model is the surfacing industry, which includes segments like the flooring materials and decorative laminates.
About the flooring industry in particular, we can start saying that by “floor covering” it’s intended any finish material applied over a floor structure in order to provide a walking surface.
Today in the market there is an enormous amount of variety of materials employed, and the choice of the kind of floor for a customer is influenced by many factors, such as cost, , comfort, cleaning effort, ease of installation, endurance, noise insulation etc...
The main kinds of floors available today on the markets are:

- *Carpets*, which are soft floors made of bound carpet fibers or stapled fibers; this type of flooring is typically used indoors and can be used in both high and low traffic areas. It typically lasts for 15-18 years before it needs to be replaced. The quality of a carpet is usually measured in face weight, or how many fibers there are per square inch
- *Wood floors*, which are a common choice as a flooring material and can come in various styles, colors, cuts, and species (i.e, hardwood flooring, solid wood flooring, rotary-peel, sliced-peel, dry solid-sawn).
- *Engineered wood floors*, consisting of two or more layers of wood adhered together. Typically, engineered wood flooring uses a thin layer of a more expensive wood bonded to a core made from cheaper wood. Engineered wood is characterized by a greater stability, achieved by running each layer at a 90° angle to the layer above
- *Laminate flooring*, which are floor coverings similar to hardwood but made with a plywood or medium density fiberboard ("MDF") core with a plastic laminate top layer.

- *Hard flooring*, that includes concrete or cement, ceramic tile, glass tiles, and natural stone products.
- *Resilient flooring*, which is made of elastic materials and therefore is characterized by a degree of flexibility called resilience.

3.2 Dynamics of innovation in the examined field

Flooring and *surfacing* have seen a lot of innovation in recent years: *tile design* has progressed substantially – becoming sharper and more realistic through advancements in digital printing. Emerging products have brought more and more functions to the market, in order to remedy problems due to intrinsic limits of the materials: some examples are *waterproofing*, *slippage prevention*, *stain proofing*, *crack prevention* and so on.

Laminates are becoming more and more realistic, both in look and in texture, and are more durable, thanks to the progresses achieved in terms of resistance to scratches and perturbations in general.

One of the more trending innovations in the surfacing industry right now is *sintered stone*, which is a new product category for interior surfaces becoming widely popular, especially in United States and Canada. *Sintering* is a manufacturing process based on atomic diffusion of particles that occurs most quickly at higher temperatures.

It presents many innovative features, among which the main ones that deserve to be mentioned are:

- *Availability in a wide range of custom appearances* that allow it to look like natural stone, wood grain and other materials that have an appealing aesthetic to customers;
- *Superior hardness and durability*, resistance to bacteria and dirt;
- *Environmental friendliness*, due to the fact that rare natural resources (like hardwood or natural stone) are not employed in the production process.

There are also a lot of innovative materials that haven't been commercialized yet, since they're still in the experimentation phase, but they present very promising and innovative features that could potentially lead them to revolutionize the market. Some of them could have many applications, from interior surfacing to the construction and building industry.

Some examples are:

- *Translucent wood*, which has been invented by A group of researchers from KTH Royal Institute of Technology in Stockholm who developed a process that removes the chemical lignin from a wood veneer, causing it to become very white. This material could potentially have an enormous impact on the way architectural projects are developed.
- *Biologically produced furniture*, developed by Terreform One and Genspace, thanks to a low energy, pollution-free innovative process. So far two pieces of furniture have been created with this material: a chaise lounge and a small chair for kids.
- *Self-healing concrete*, invented by Dr. Schlangen at Delft University. It has been estimated that this invention could lead to save $90 million annually. Concrete degradation is one of the most costly problems of our time. Concrete will always crack, although less so if well-designed and well-constructed. This promising new technology uses bacteria that produce limestone if triggered by contact with water and air, and in doing so they repair the crack.

Figure 10 – Biologically produced furniture

3.3 Classification of examined materials and products

The products being analyzed belong to the following families of materials:

- Glass
- Artificial and engineered stone
- Concrete
- Grès
- Engineered wood and wood-plastic composite
- Laminates
- Steel
- Other composite materials

The fields of applications of the selected products are of various kinds and are summarized below:

- Generic flooring
- Bathroom flooring
- Residential interior coating
- Residential exterior
- Windows and residential glazing
- Ventilated facades
- Bathroom flooring
- Kitchen sinks
- Kitchen tops and decor
- Exterior coating
- High security areas
- Prefabrications
- Furniture
- Railway stations
- Airports
- Nautical sector

- Glass floors

3.4 Industry-related issues relevant to the research

Some issues relative to the surfacing industry were encountered during the collection of information through technical documents and literature, and they mostly regard the *nature of innovation cases* and the *timing of entry*:

- *Nature of innovation cases*: innovations in the surfacing industry are often about introducing improvements in the properties of the material which the product is made of, therefore most innovative products found are to be classified as *incremental innovations* and therefore couldn't be used in the dataset, because the research is based on the analysis of *radical innovations*. Some examples are given by various innovative kitchen tops that are emerging in the industry lately, that are all basically improved versions of standard kitchen tops and, despite them revealing themselves very successful, cannot be considered as real radical innovations.
- *Timing of entry*: Most radical innovation cases individuated couldn't be used for the analysis because they're very recent innovations and they either didn't reach the commercialization yet or they entered the market recently, making it impossible to establish a success or failure situation yet. Some examples are the three innovative cases presented in the previous paragraph – translucent wood, biologically produced furniture and self-healing concrete – that were excluded from the analysis because they haven't reached a real commercialization yet or because there weren't reliable sources that confirmed a clear success or failure.

Chapter 4: Methodological approach

4.1 Individuating and selecting case studies

The main sources used to collect information about possible case studies were or course university papers, scientific articles, but also a lot of specialist journals, online shops with customer reviews, retailers sites, experts and reviewers communities and so on.
All products collected have been categorized by *family of material* and by *fields of application*, as already mentioned.
Categorization of collected cases was crucial for individuating the right *predecessor*, that can vary depending on the field of application considered. Individuating the right predecessor was a fundamental step in order to develop a coherent *functional analysis* of the new product features introduced; the basic criteria adopted has been to look at *product generations* chronologically and find the product in respect of which the improvements introduced should be considered. (i.e, *CPL laminates* can be considered successors of *HPL laminates*, *self-cleaning windows* are successors of *traditional windows*). In accordance with the principle of product generations and with the concept of s-curves, whenever two or more nearly simultaneous innovations have been individuated (i.e, *hydrophobic* and *hydrophilic self-cleaning glass*), the functional analysis has not been done by comparing those products between them but in comparison with the common predecessor (in this case, *traditional glass*).

Product Name	Family of Material	Main fields of application	Predecessors
Laminated Glass	Glass	High security areas (banks, jewellery shops etc…)	Traditional glass

Table 2 – Laminated Glass Case Study

4.2 The adopted framework

The framework that was followed to develop the analysis is the same one adopted by Casagrande (2017), and previously by Borgianni (2013): this way to proceed has been chosen in order to ensure *continuity* with their study and have *comparable results*. Otherwise, there wouldn't have been the chance to compare the work with other studies. As Casagrande and Borgianni did, only products with *at least three features* subject to modification have been considered as radical innovation to implement in the research work.

Since the main goal of the study is to describe how an innovative product differs from its predecessor, the analysis has been developed through a *two-dimensional space*:

- The *first dimension* is characterized by a *functional logic* describing how the features affect *user satisfaction*, following the *TRIZ theory*.
- The *second dimension* is characterized by the *actions* that designers can perform to obtain new products: the tool that has been considered as the best effective to "explore" this dimension is the "Four Actions Framework", which as already mentioned has been firstly proposed by Kim & Mauborgne (2005) with the aim of supporting business modifications, but later applied also to specific products (Borgianni et al., 2012).

As regards the *first dimension*, the TRIZ theory affirms that a feature has to be associated to:

- *a useful function* (UF) if a positive outcome is delivered;
- a *harmful function* (HF) if it is a way to attenuate drawbacks provoked by the system;
- a *resource* (RES) if it reduces the impact due to the consumption of the resources in charge of final users.

As regards the *second dimension*, the designers can perform four different kinds of actions:

- *Create*, which means introducing a new feature unknown by industry until then;
- *Raise*, which means improving an attribute already present in the industry;
- *Reduce*, which means worsen an attribute already present in the industry;
- *Eliminate*, which means remove a feature;

By crossing the functional dimension and the design actions we can obtain 12 crossed interrelationships, or "categories":

1. *Create a useful function*
2. *Create a harmful function*
3. *Create a resource*
4. *Raise a useful function*
5. *Raise a harmful function*
6. *Raise a resource*
7. *Reduce a useful function*
8. *Reduce a harmful function*
9. *Reduce a resource*
10. *Eliminate a useful function*
11. *Eliminate a harmful function*
12. *Eliminate a resource*

4.3 Approach used to assess commercial success and failure

The main approach used to associate identified products to *success* or *failure* situations is to find reliable information through bibliography, papers and specialized journals providing evidence that a given product was accepted or refused by the market. Obviously, for each product, we adopted a rigorous approach trying to find more than one source confirming the nature of the market appraisal. Of course, that has been relatively easy in case of famous and declared successes (i.e, laminated glass, HPL and CPL laminates, artificial stone surfaces); instead, it has been much more complicated when dealing with very *niche products* (i.e, translucent concrete, non-fired eco bricks, Aquastep waterproof laminates), that are less popular and for which it's difficult to find reliable information, or with *recent* and *ongoing innovations*, that are still being "evaluated" by the market right now.

4.4 Functional analysis

As mentioned above, the functional analysis has been done by categorizing each new *product feature change* that has been introduced into one of the *12 categories* derived from the *crossed interrelationships* between *design actions* and *functional features*. Classifying correctly the action performed is a fundamental step, and it's not always trivial: there are cases in which the boundary between a useful function and a harmful function is not that trivial and the function itself can be interpreted differently looking at the many ways it impacts the customer satisfaction.

Some representative cases are presented and discussed below:

Action	Functional Analysis	Feature	Description of feature changes
Create	HF	Integrity	The glass doesn't break into pieces when subjected to external perturbations because it's held in place by an interlayer (unlike traditional glass)
Raise	HF	Safety	Safety of the product is increased because since the glass doesn't break into pieces accidents are less likely to happen
Raise	UF	Sound insulation	Thanks to its material properties the interlayer also provides sound attenuatior
Raise	UF	Capability to block UV rays	The interlayer can block most ultraviolet radiations, unlike traditional glass
Reduce	RES	Cheapness	Price for laminated glass is higher than standard glass because of the added interlayers

Figure 11 – Laminated Glass Functional Analysis

Laminated glass, for instance, is a case in point for the importance of distinguishing conceptually "Raise" and "Create" actions: at first sight, in fact, the better integrity of the laminated glass could seem like an improvement associated to a "Raise" action. Actually, the feature "integrity" must be associated to a "Create" action because traditional glass breaks into pieces, while laminated glass doesn't: therefore, the fact that laminated glass it's held in place by an interlayer, unlike traditional glass, is conceptually a totally new feature and not an improvement of an old one.

Action	Functional Analysis	Feature	Description of feature changes
Create	UF	Ability to change degree of transparency	"Smart" glass that can change from light to dark (clear to opaque) and back again, at the push of a button
Raise	HF	Environmental friendliness	Less need for air conditioning because it's able to reflect back all the light
Create	RES	Interoperability	It can easily be controlled by a smart-home system or a sunlight sensor
Reduce	RES	Cheapness	Technology-intensive product, therefore very expensive
Reduce	RES	Ancillary costs	Higher installation and maintenance costs
Reduce	HF	Reliability	Occasional technical glitches (new technology still being experimented)
Reduce	RES	Time to be waited before the functioning of the product delivers the expected outcomes	Changes are not immediate, there's a certain time needed to change from clear to opaque and back again
Reduce	HF	Product life	Shorter life of the product than most homeowners would expect from traditional glazing

Figure 12 – Smart glass functional analysis

About electrochromic smart glass, it has been highlighted by various sources that, despite many positive features introduced, overall the product has not reached a large commercialization yet because of some *technical glitches*: these glitches are due to the new technology still being experimented. This problem has been expressed through the "*Reliability" feature*, which is a harmful function, according to Borgianni's classification.

4.5 Logistic Regression

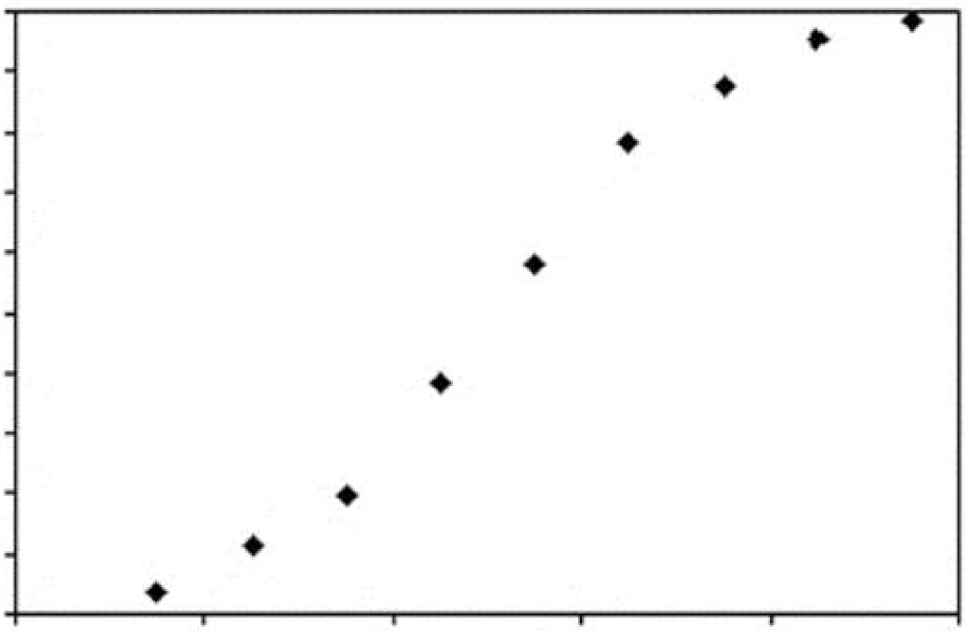
To ensure continuity with the work of Casagrande and Borgianni, the statistical method employed to develop the model is the *logistic regression*: logistic regression is a very popular tool, widely documented in the statistic literature, that uses a *logistic function* to model a *binary dependent variable* – in this case indicating success or failure – as a function of *independent explanatory variables*, also called *covariates*. It provides in return success percentages, ranging from 0% to 100%.

Logistic regression doesn't require assumptions about the distributions of the explanatory variables.

The logistic function is used to transform an S-shaped curve into an approximately straight line and is defined as the natural logarithm of the odds:

$$logi(p) = \ln(p / (1 - p)) = \alpha + \beta x$$

where p is the probability of the desired outcome.



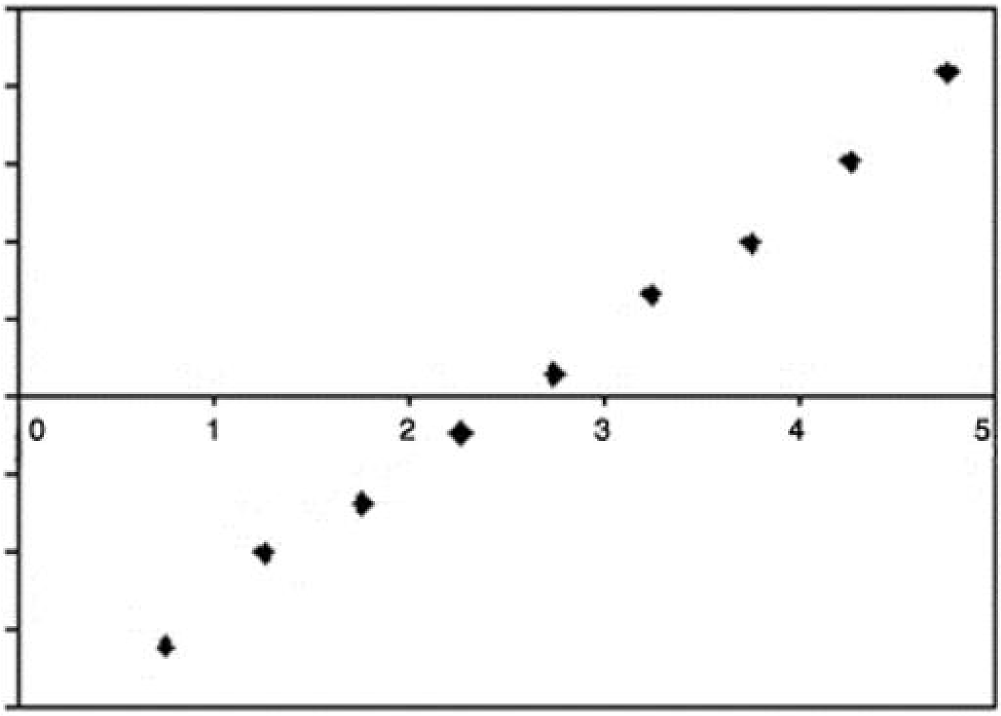


Figure 13 – Logistic Function

The predicted probability of success is equal to:

$$probability\ of\ success = \frac{e^z}{1 + e^z}$$

To implement the model, SPSS software was used. Two different attempts have been made:

- *First attempt*: following the same approach as the previous research woks, 60% of the overall cases randomly selected were used to build the model and the remaining cases for the cross-validation. Therefore, 12 success cases and 4 failure cases were used for the implementation. In this case SPSS software only completed the "step 0" and was unable to get to the "step 1" and provide the predictors for the regression equation.
- *Second attempt*: all 27 available cases (20 successes, 7 failures) were used for the implementation of the model, without applying the cross-validation. This time SPSS software got to the "step 1" and provided predictors and the regression equation.

Chapter 5: Results of the model

5.1 Regression output

The *regression output* of the second attempt is presented below:

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	CREATE_UF	-12,857	9134,177	,000	1	,999	,000
	CREATE_HF	-23,218	29163,800	,000	1	,999	,000
	CREATE_RES	37,562	22499,161	,000	1	,999	2,056E+16
	RAISE_UF	21,135	6491,799	,000	1	,997	1509039873
	RAISE_HF	73,241	15633,076	,000	1	,996	6,428E+31
	RAISE_RES	16,144	12585,344	,000	1	,999	10264473,89
	REDUCE_UF	-35,520	39811,155	,000	1	,999	,000
	REDUCE_HF	3,209	17828,113	,000	1	1,000	24,755
	REDUCE_RES	-42,679	7447,416	,000	1	,995	,000
	ELIMINATE_UF	-57,626	14716,896	,000	1	,997	,000
	ELIMINATE_RES	-142,184	52494,152	,000	1	,998	,000
	Constant	4,679	23507,928	,000	1	1,000	107,625

a. Variable(s) entered on step 1: CREATE_UF, CREATE_HF, CREATE_RES, RAISE_UF, RAISE_HF, RAISE_RES, REDUCE_UF, REDUCE_HF, REDUCE_RES, ELIMINATE_UF, ELIMINATE_RES.

Figure 14 – Regression Output

At the current state of the dataset, the model has no significance yet because:

- All "Create" and "Raise" actions coefficients should have *positive sign*, while "Reduce" and "Eliminate" actions should have *negative sign*. Instead, as it's shown in the *regression output*, there are some incoherencies.
- Most values of the B column are very high and random, and the S.E as well.
- The sig. column should have values < 0.05 for statistical significance.

The *issues* of the model at the current state are mainly related to the *failure cases* and the *small unbalanced dataset*.
In particular, the following aspects about failure cases must be highlighted:

- *Accessibility and availability of information*: as mentioned previously, most firms are reluctant in releasing information about failed innovative products and, being this industry a very niche market, most papers about innovation in the flooring industries only cite success cases.
- *Actual nature of the failure cases*: as a consequence of the previous point, most "failure" cases found are not total and declared failures, but products that are still potentially successful in terms of innovation content and present issues mostly related to process efficiency. Therefore most of them are "borderline" cases for which it's difficult to establish clearly a success or failure situation: in fact, they don't have a real market yet, but have some applications and are still in an experimentation phase.

As regards the dataset, these are the main issues:

- *Only 27 cases* identified in total by now: the sample size at the moment is too small and at the same time there are too many covariates to obtain statistically significant predictors.
- *Distribution of the binary variable* (20 successes, 7 failures): the dataset is unbalanced and the failure cases are too few to allow the model to find a recognizable "pattern" in the features introduced.

5.2 Next Steps

Given the current results of the model, some obvious questions come to mind: what sample set should be used to *maximize the probability* of obtaining *significant predictors*? How to deal with an *unbalanced dataset*?

The *appropriate sample set* to use in a logistic regression is a very *debated topic* among researchers. In general, models with n < 30 cases like the current dataset have very *little statistical significance*, so the database should be expanded for sure.
Some authors (Peduzzi et al., 1996) proposed a generic formula for the *minimum sample size calculation* in the logistic regression, that keeps in count both the *number of independent varibles* (covariates) and the *unbalance in the distribution* of positive/negative binary dependent variables.
Let *p* be the *smallest of the proportions* of negative or positive cases and *k* the *number of covariates* then the *minimum number of cases N* to include is:

$$N = 10\,\frac{k}{p}$$

Therefore, in this specific case:

$$p\ (success) = \frac{20}{27} = 0.74$$

$$p\ (failure) = \frac{7}{27} = 0.26 < 0.74$$

$$k = 12$$

$$N = 10\,\frac{12}{0.26} = 462$$

If we assume to build a database with equal number of success and failure cases, we can reduce the number to:

$$N = 10\,\frac{12}{0.5} = 240$$

Conclusion

This research aims to deliver a first attempt to the development of an industry-specific decision support model, potentially able to guide innovative firms in *predicting* new *technological paradigms*.

Since the sample size of collected case studies is still very small, the model at the moment is far from constituting a concrete support tool, and the results are not statistically significant yet.

The model erroneously interpreted the impact of some design actions: for example, the "*Create Useful Function*" variable has a positive impact on the probability of success and the regression should have predicted a coefficient with positive sign in order to get a coherent output, but instead the predicted coefficient has a minus sign.

The reason for this, as previously highlighted, is probably due to the fact that most failure cases didn't achieve a successful commercialization but tried to be radically innovative by creating something totally new and therefore "Create" actions are often featured in the functional analysis. This has been a problem for the model, and it has led to an *incorrect interpretation* of the variable. Those kinds of *misinterpretations of patterns* are a *common problem* when dealing with *small and unbalanced datasets* like in this case.

However, this actually was the expected output at the current state: in fact, by now, only 27 cases (20 successes, 7 failures) were collected and, as highlighted in the last chapter, literature suggests a minimum sample size of about 462 cases in order to get statistical significance with the current variables distribution (Peduzzi et el., 1996).

As expected, there have been many issues while collecting case studies: the main one is related to the identification of failure cases. In fact, most firms are reluctant in releasing information about failed innovative products and, being this industry a very niche market, most papers about innovation in the flooring and laminates industries only cite success cases.

About success cases in particular, the main problem was related to their nature: a lot of cases found were discarded before the implementation, because they were actually incremental innovations, and only radical innovations should be included in the model for *methodological coherence*.

A possible way to quickly collect many more case studies would be to create a *multidisciplinary research group* and involve in the study experts and designers that work in the surfacing or decorative laminates industry: this would help both the identification of cases, that otherwise would be very difficult to find through literature, and the *functional analysis*, thanks to the competence of designers in the interpretation of the functional features subject to modification.

However, some interesting facts about the dynamics of the design process in the surfacing industry have already been individuated in this preliminary phase: it has been noticed, for instance, that products belonging to this industry rarely feature the "Eliminate" action in the functional analysis, because the innovations are usually about changing the physical properties of the material, therefore "Raise" and "Reduce" actions are by far the most common, differently from what happens for products belonging to other industries.

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Appendix - List of case studies

Case study #1 - Laminated Glass (Success)

Action	Functional Analysis	Feature
Create	HF	Integrity
Raise	HF	Safety
Raise	UF	Sound insulation
Raise	UF	Capability to block UV rays
Reduce	RES	Cheapness

Feature	Description of feature changes
Integrity	The glass doesn't break into pieces when subjected to external perturbations because it's held in place by an interlayer (unlike traditional glass)
Safety	Safety of the product is increased because since the glass doesn't break into pieces accidents are less likely to happen
Sound insulation	Thanks to its material properties the interlayer also provides sound attenuation
Capability to block UV rays	The interlayer can block most ultraviolet radiations, unlike traditional glass
Cheapness	Price for laminated glass is higher than standard glass because interlayers

Case study #2 - Pilkington Activ Glass (Success)

Action	Functional Analysis	Feature
Create	UF	Self-cleaning surface
Raise	RES	Ease of rinsing
Raise	RES	Need for auxiliary products
Raise	HF	Durability
Reduce	RES	Cheapness

Feature	Description of feature changes
Self-cleaning surface	Ability to break down and loosen organic dirt on glass surfaces thanks to photocatalysis
Ease of rinsing	More efficient rinsing of the glass surface thanks to its hydrophilicity
Need for auxiliary products	The self-cleaning surface reduces the need for cleaning products frequently used for traditional glass
Durability	Increased durability of the coating on the glass thanks to a patented process which makes the coating an integral part of the glass
Cheapness	Price for self-cleaning glass is higher than standard glass due to the complexity of the production process and the added "prestige" of the final product

Case study #3 - Hydrophobic self-cleaning glass (Failure)

Action	Functional Analysis	Feature
Create	UF	Self-cleaning surface
Raise	HF	Resistance to scratches
Raise	RES	Need for auxiliary products
Reduce	RES	Cheapness
Eliminate	UF	Transparency

Feature	Description of feature changes
Self-cleaning surface	Ability of the surface to use energy from the sun and water rain to self-clean
Resistance to scratches	the material of the coating is more resistant to scratches than traditional glass
Need for auxiliary products	The self-cleaning surface reduces the need for cleaning products frequently used for traditional glass
Cheapness	Batch processing a hydrophobic material is a costly and time-consuming technique so price is ultimately very high
Transparency	The coatings produced are usually not transparent but hazy, precluding wide applications on windows

Case study #4 - Low-e Sputter Glass (Success)

Action	Functional Analysis	Feature
Raise	UF	Heat holding
Raise	HF	Environmental friendliness
Reduce	HF	Susceptibility to degradation
Reduce	RES	Lead time
Reduce	RES	Cheapness

Feature	Description of feature changes
Heat holding	Limitation of heat escaping through the windows
Environmental friendliness	The product is environmental friendly due to its efficiency energy-wise
Susceptibility to degradation	The coating is more susceptible to degradation, due to either oxidation in the environment or to scratches, that could reduce shelf life of the glass
Lead time	Special care required that increases lead time for the customer
Cheapness	Expensive kind of glass

Case study #5 - Low-e Pirolitic Glass (Success)

Action	Functional Analysis	Feature
Raise	UF	Heat holding
Raise	HF	Environmental friendliness
Reduce	UF	Expected quality
Reduce	RES	Cheapness

Feature	Description of feature changes
Heat holding	Limitation of heat escaping through the windows
Environmental friendliness	The product is environmental friendly due to its efficiency energy-wise
Expected quality	Less excellence in terms of performance compared to low-e sputter glasses
Cheapness	Expensive kind of glass

Case study #6 - Photochromic Smart Glass (Failure)

Action	Functional Analysis	Feature
Create	UF	Ability to respond to changes in light
Raise	HF	Environmental friendliness
Reduce	RES	Time to be waited before the functioning of the product delivers the expected outcomes
Reduce	RES	Cheapness
Reduce	HF	Reliability

Feature	Description of feature changes
Ability to respond to changes in light	The material is able to respond to changes in light reducing glare from the sun (it darkens when you move from a dim light to a bright one)
Environmental friendliness	Energy efficient; less need for air conditioning
Time to be waited before the functioning of the product delivers the expected outcomes	Changes are not immediate, there's a certain time needed to change from clear to opaque and back again
Cheapness	Technology-intensive product, therefore very expensive
Reliability	Limited reliability because this technology works fine on small, eyeglass-sized pieces of glass but too little experimentation has been done on windows-sized glass

Case study #7 - Electrochromic Smart Glass (Failure)

Action	Functional Analysis	Feature
Create	UF	Ability to change degree of transparency
Raise	HF	Environmental friendliness
Create	RES	Interoperability
Reduce	RES	Cheapness
Reduce	RES	Ancillary costs
Reduce	HF	Reliability
Reduce	RES	Time to be waited before the functioning of the product delivers the expected
Reduce	HF	Product life

Feature	Description of feature changes
Ability to change degree of transparency	"Smart" glass that can change from light to dark (clear to opaque) and back again, at the push of a button
Environmental friendliness	Less need for air conditioning because it's able to reflect back all the light
Interoperability	It can easily be controlled by a smart-home system or a sunlight sensor
Cheapness	Technology-intensive product, therefore very expensive
Ancillary costs	Higher installation and maintenance costs
Reliability	Occasional technical glitches (new technology still being experimented)
Time to be waited before the functioning of the product delivers the expected outcomes	Changes are not immediate, there's a certain time needed to change from clear to opaque and back again
Product life	Shorter life of the product than most homeowners would expect from traditional glazing

Case Study #8 - Liquid Crystal Privacy Glass (Success)

Action	Functional Analysis	Feature
Create	UF	Privacy control
Raise	RES	Need for auxiliary products
Raise	RES	Working speed
Create	RES	Interoperability
Reduce	RES	Cheapness

Feature	Description of feature changes
Privacy control	Allows light flow while assuring people's privacy thanks to the liquid crystal
Need for auxiliary products	No window coverings needed thanks to privacy control
Working speed	Privacy at the flip of a switch, the changing is immediate
Interoperability	It can easily be controlled by a smart-home system or a sunlight sensor
Cheapness	Technology-intensive product, therefore very expensive

Case study #9 - Artificial Stone Surfaces (Success)

Action	**Functional Analysis**	**Feature**
Raise	RES	Cheapness
Raise	HF	Environmental friendliness
Raise	UF	Aesthetical irregularities
Eliminate	UF	Feeling of distinction
Reduce	RES	Need for special care
Reduce	HF	Resistance

Feature	**Description of feature changes**
Cheapness	It's cheaper than natural stone
Environmental friendliness	Eco-friendly because the customer is not depriving the planet of important resources
Aesthetical irregularities	More regularity in color and thickness
Feeling of distinction	Feeling of distinction and satisfaction due to having a natural material in the house
Need for special care	Special care is required for cleaning the surfaces
Resistance	Less resistance of the material in comparison with natural stone
Aesthetic qualities	Elegant, appealing and prestigious design

Case study #10 - Sintered Stone Surfaces (Success)

Action	**Functional Analysis**	**Feature**
Raise	UF	Aesthetic qualities
Raise	HF	Environmental friendliness
Raise	HF	Resistance to bacteria
Raise	HF	Product life
Eliminate	UF	Feeling of distinction
Reduce	RES	Cheapness

Feature	**Description of feature changes**
Aesthetic qualities	Elegant, appealing and prestigious design
Environmental friendliness	Eco-friendly because the customer is not depriving the planet of important resources
Resistance to bacteria	Non porous material, resistant to staining, mould and bacteria and therefore it's easily cleaned
Product life	Long lasting and completely weather proof
Feeling of distinction	Feeling of distinction and satisfaction due to having a natural material in the house
Cheapness	Innovative material, generally pretty expensive

Case Study #11 - Fiber Reinforced Concrete (Success)

Action	Functional Analysis	Feature
Raise	HF	Integrity
Raise	HF	Impermeability
Raise	UF	Ductility
Raise	HF	Stability
Reduce	RES	Cheapness
Eliminate	RES	User friendliness
Reduce	RES	Workability
Reduce	HF	Resistance to corrosion

Feature	Description of feature changes
Integrity	Increased structural integrity thanks to the fibers reducing the propagation of cracks
Impermeability	Reduction of permeability of the concrete
Ductility	Better ductility of the material
Stability	The material is resistant to external perturbations, freeze-thaw resistance, resistance to explosive spalling in case of a fire)
Cheapness	Since it's fiber-reinforced, it's more expensive than traditional concrete
User friendliness	Very difficult to self-mix for the customer; professional help is required
Workability	Reduced workability of the material
Resistance to corrosion	Possibility of corrosion stains if the fibers are exposed at the surface

Case Study #12 - Photocatalytic Concrete (Failure)

Action	Functional Analysis	Feature
Raise	UF	Air quality
Raise	UF	Stability of aesthetic appearance
Raise	UF	Temperature retaining
Reduce	RES	Cost effectiveness
Reduce	RES	Limited efficiency of the photocatalysis

Feature	Description of feature changes
Air quality	Air quality improvement thanks to photocatalysis
Stability of aesthetic appearance	It maintains aesthetic appearance of structures for a long time thanks to self-cleaning properties
Temperature retaining	Reflecting of heat coming from the sun allows surface to retain its low temperature during the summer
Cost effectiveness	The production process is still not cost effective
Limited efficiency of the photocatalysis	The process itself is still not sufficiently efficient for large commercial applications

Case study #13 - Grès Porcelain stoneware (Success)

Action	Functional Analysis	Feature
Raise	HF	Resistance to thermal shocks
Raise	HF	Resistance to fire
Raise	HF	Safety
Raise	UF	Slip-resistance
Raise	UF	Resistance to dirt
Raise	UF	Aesthetical variety
Reduce	HF	Resistance to scratches
Reduce	HF	Integrity of the surface colors
Reduce	RES	Need for maintenance

Feature	Description of feature changes
Limited efficiency of the photocatalysis	The process itself is still not sufficiently efficient for large commercial applications
Resistance to thermal shocks	Resistance to weather conditions and thermal shocks
Resistance to fire	Porcelain Grès is more resistant to fire
Safety	It doesn't release toxic substances in case of fire
Slip-resistance	Porcelain grès in not a slippery material
Resistance to dirt	Easy to clean and resistant to dirt thanks to the glazing preventing dirt going inside the tiles
Aesthetical variety	More variety of colors, styles and textures than natural grès
Resistance to scratches	Limited resistance to scratches
Integrity of the surface colors	Tendency to lose color with time
Need for maintenance	Requires maintenance with specific wax

Case Study #14 - Engineered Wood (Success)

Action	**Functional Analysis**	**Feature**
Raise	HF	Environmental friendliness
Raise	HF	Resistance to moisture
Raise	RES	Ancillary costs
Raise	RES	Replenishing time
Eliminate	UF	Feeling of distinction
Reduce	UF	Opportunity for refinishing
Reduce	RES	Need to integrate with natural materials

Feature	**Description of feature changes**
Environmental friendliness	less use of natural wood
Resistance to moisture	Reduction of moisture problems associated with conventional hardwood
Ancillary costs	Reduced installation costs
Replenishing time	Shorter replenishing time than hardwood
Feeling of distinction	Feeling of distinction and satisfaction due to having a natural material in the house
Opportunity for refinishing	Thin veneers prevent refinishing opportunities
Need to integrate with natural materials	Core layers must still be fashioned from high-quality wood

Case study #15 - Wood-plastic composite (Success)

Action	**Functional Analysis**	**Feature**
Raise	HF	Resistance to corrosion
Create	UF	Variety of colors
Raise	RES	Need for painting
Raise	HF	Environmental friendliness
Create	UF	Variety of shapes
Eliminate	UF	Feeling of distinction
Reduce	HF	Stiffness
Reduce	UF	Degradability
Reduce	HF	Fire safety

Feature	**Description of feature changes**
Resistance to corrosion	Increased resistance to corrosion
Variety of colors	Available in many varieties of colors, unlike natural wood
Need for painting	No need to paint since products are available in many varieties of colors
Environmental friendliness	It can be made using recycled plastics and the waste products of the wood industry
Variety of shapes	The material can be molded to meet almost any desired shape, unlike natural wood
Feeling of distinction	Feeling of distinction and satisfaction due to having a natural material in the house
Stiffness	Decreased mechanical stiffness and strength due to water absorption properties of the material
Degradability	Vulnerability to UV degradation of the polymer component
Fire safety	Higher fire hazard properties than wood alone, as plastic has a higher chemical heat content and can melt

Case Study #16 - High Pressure Laminate Flooring HPL (Success)

Action	Functional Analysis	Feature
Raise	UF	Customization
Raise	RES	Ease of installation
Raise	HF	Resistance to scratches and abrasion
Raise	RES	Ease of cleaning
Reduce	HF	Brittleness

Feature	Description of feature changes
Customization	available in numerous designs, patterns, colours and textures
Ease of installation	No particular skill required to install
Resistance to scratches and abrasion	It's more resistant to scratches and abrasion than many other flooring materials
Ease of cleaning	Easy to maintain and clean
Brittleness	It is a brittle material hence is prone to clipping

Case Study #17 - Continuous Pressure Laminate CPL

Action	**Functional Analysis**	**Feature**
Raise	RES	Ease of finishing
Raise	UF	Applicability in different shapes
Raise	UF	Versatility
Raise	RES	Cheapness
Reduce	HF	Resistance

Feature	**Description of feature changes**
Ease of finishing	Continuous finishing facilitated
Applicability in different shapes	Easy application also for curved surfaces
Versatility	Increased versatility in available lengths
Cheapness	It's a cheap flooring material
Resistance	The material is less resistant to scratches and to abrasion than HPL because the production process is characterized by a lower pressure value

Case Study #18 – Inox Steel Surfaces (Success)

Action	Functional Analysis	Feature
Raise	HF	Resistance to corrosion and oxidation
Raise	RES	Ease of cleaning
Raise	HF	Product life
Raise	RES	Need for maintenance
Raise	HF	Environmental friendliness
Reduce	HF	Reliability

Feature	Description of feature changes
Resistance to corrosion and oxidation	When compared with mild steel, stainless steels have higher resistance to corrosion and oxidation
Ease of cleaning	Stainless steel is a particularly easy to clean and hygienic material, one of the reasons why it's also used in the food industry
Product life	Increased durability
Need for maintenance	Limited maintaining needed
Environmental friendliness	the material is known for being easily recyclable
Reliability	Risk of ferrous contamination that can reduce resistance to corrosion and originate aesthetic defects

Case Study #19 - Aluminium Honeycomb Sandwich Panels (Success)

Action	Functional Analysis	Feature
Raise	RES	Workability
Raise	HF	Damage tolerance
Raise	HF	Failure behaviour
Raise	HF	Resistance to inflammability
Reduce	HF	Susceptibility to dents
Reduce	RES	Need for special care

Feature	Description of feature changes
Workability	It can be manufactured in complex geometries
Damage tolerance	It can be damaged without immediate loss of performance
Failure behaviour	usually benign, not catastrophic failure
Resistance to inflammability	It can be non-inflammable when produced without adhesives
Susceptibility to dents	They are susceptible to dents during storms and hurricanes
Need for special care	The joints have to be carefully sealed and adequate water proofing has to be done so that there is no water penetration during the rains

Case study #20 - Fenix Nanotech Laminates (Success)

Action	**Functional Analysis**	**Feature**
Raise	HF	Resistance to scratches
Create	HF	Resistance to fingerprints
Create	UF	Thermal healing of superficial microscratches
Raise	UF	Resistance to heat
Reduce	RES	Cheapness

Feature	**Description of feature changes**
Resistance to scratches	it can withstand serious knocks and scratches
Resistance to fingerprints	Anti-fingerprint material thanks to the innovative Electron Beam Curing process
Thermal healing of superficial microscratches	The surface of the material is scattered with a dense grid of crosspolymers with their own memory, which can be reactivated by the application of heat.
Resistance to heat	The material is more resistant to heat than a traditional laminate
Cheapness	More expensive than traditional laminates because nanotechnology is involved in the production process

Case Study #21 - Corian Surfaces (Success)

Action	Functional Analysis	Feature
Raise	HF	Resistance to stains
Create	UF	Seam absence
Raise	HF	Prevention against fungus
Raise	RES	Ease of repair
Reduce	HF	Susceptibility to direct heat
Reduce	RES	Cheapness
Eliminate	UF	Feeling of distinction

Feature	Description of feature changes
Resistance to stains	Corian is a non porous material, and that makes it very stain-resistant
Seam absence	the countertops feature a nearly seamless joint
Prevention against fungus	It's able to prevent the growth of bacteria and fungus, therefore it's very hygienic
Ease of repair	Being homogeneous in thickness, it can easily be repaired with superficial abrasive treatments after accidental deterioration
Susceptibility to direct heat	it can get damaged easily, when exposed to hot pans and vessels
Cheapness	Though the price of Corian is not as high as that of granite, it can be costlier than the other types of materials which are used in building the countertop
Feeling of distinction	Feeling of distinction and satisfaction due to having a natural material in the house.

Case Study #22 - Non-Fired Eco Bricks (Failure)

Action	Functional Analysis	Feature
Raise	RES	Resource conservation and optimization
Raise	HF	Environmental friendliness
Raise	RES	Construction time
Reduce	RES	Cheapness
Reduce	RES	Efficiency of the production
Reduce	RES	Need for technical requirement and specialized tools

Feature	Description of feature changes
Resource conservation and optimization	80% of the raw materials are made up from several kinds of by-products from other industries
Environmental friendliness	Using industrial waste allows the minimization of environmental pollution
Construction time	Using non-fired bricks shorten the construction time of the buildings
Cheapness	Traditional bricks are cheaper
Efficiency of the production	The output of non-fired bricks was about 6.8 billion cubes, while the output of burned clay bricks was 18 billion of cubes.
Need for technical requirement and specialized tools	The use of non-fired bricks requires strict technical requirement. Most builders are familiar with burned clay bricks and simple tools while non-fired ones require specialized construction tools

Case Study #23 - Translucent Concrete (Failure)

Action	**Functional Analysis**	**Feature**
Create	UF	Light transmitting properties
Raise	RES	Environmental friendliness
Reduce	RES	Cheapness
Reduce	RES	Need for special skills

Feature	**Description of feature changes**
Light transmitting properties	Translucent concrete allows to create ambiences that are better and more naturally lit
Environmental friendliness	Light transmitting properties also can provide energy savings.
Cheapness	Translucent concrete is very costly because of the optical fibers.
Need for special skills	Casting of translucent concrete block is difficult for the labour so special skilled person is required

Case study #24 -Marine Plywood (Success)

Action	Functional Analysis	Feature
Raise	HF	Durability
Raise	HF	Resistance to salt
Raise	HF	Resistance to humidity and fungal rot
Reduce	RES	Need for additional enhancements
Reduce	RES	Cheapness
Reduce	RES	Time and effort needed in the production process

Feature	Description of feature changes
Durability	The material has extraordinary natural durability
Resistance to salt	This material is particularly resistant to the presence of salts
Resistance to humidity and fungal rot	The material's properties are able to prevent all those problems linked to humidity and fungus
Need for additional enhancements	Needs to be covered by laminates (such as Sunmica) so as to enhance its beauty and to increase its life
Cheapness	Very costly material due to its highly rich and specific properties
Time and effort needed in the production process	Furniture has to be created manually using pieces of plywood, which means that making most plywood furniture is not a one-day activity

Case study #25 - Shaw Repel Laminates (Failure)

Action	Functional Analysis	Feature
Create	HF	Water repellency
Raise	UF	Aesthetic qualities
Reduce	RES	User friendliness
Reduce	RES	Need for care
Reduce	UF	Level of effective quality

Feature	Description of feature changes
Water repellency	The laminate is water repellent
Aesthetic qualities	a high gloss finish called OptiGuard is placed over the laminate to dramatically bring out its natural wood look
User friendliness	Shaw’s website is not clear on exactly what you need to do before installing: this murkiness in instruction makes installation significantly more difficult than the snap and lock method described as a Shaw laminate advantage.
Need for care	Shaw's guide has excessive set of rules on how to care for any type of flooring which makes the actual use of the product rather difficult
Level of effective quality	Most users say that the product was defective: the most common problem seems to be that a big part of the pieces ordered are bowed.

Case Study #26 - Aqua Step Waterproof Laminate (Success)

Action	Functional Analysis	Feature
Create	HF	Water repellency
Raise	UF	Natural silence
Raise	RES	Ease of re-installing
Reduce	RES	Ease of acquiring the product
Reduce	RES	Cheapness

Feature	Description of feature changes
Water repellency	In 2001 Parcolys Flooring extrusion experts invented Aqua-Step, the first 100% water resistant laminate floor.
Natural silence	Aqua-Step is 30% more sound absorbing than traditional wood laminate
Ease of re-installing	The very flexible installation system allows the customer to re-install the floor several times
Ease of acquiring the product	It is currently available through only one U.S. distributor in Massachusetts.
Cheapness	Very expensive because innovation-intensive product

Case Study #27 - Ariostea large porcelain slabs (Success)

Action	Functional Analysis	Feature
Raise	UF	Variety of design
Raise	HF	Safety
Reduce	RES	Cheapness

Feature	Description of feature changes
Variety of design	The Ultra technology, permitting the creation of porcelain floors out of 300x150 cm slabs, allows architects and designers to give free rein to their creativity permitting previously unthinkable applications
Safety	Flooring for large public areas requires excellence in terms of resistance and safety. Ariostea brings excellence in terms of performance and safety as proved by its implementation in some of the most important airports in the world (Toronto Airport in Canada, Birmingham Airport and London's Heathrow Airport are just a few examples)
Cheapness	Technology-intensive product, therefore very expensive