Breaking the dilemma between robustness and generativeness: a comparative experiment on the use of new design software at the design-gap

Pierre-Antoine Arrighi, Pascal Le Masson, Benoit Weil

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BREAKING THE DILEMMA BETWEEN ROBUSTNESS AND GENERATIVENESS: A COMPARATIVE EXPERIMENT ON THE USE OF NEW DESIGN SOFTWARE AT THE DESIGN-GAP.

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Are creative designers doomed to loose in creativity when integrated in NPD processes? While a lot of studies point the necessity to achieve both creativity and feasibility, it remains hard to make more than a frustrating trade off. Still a new generation of design software have recently been proposed to better integrate industrial designers in engineering design processes. Based on a comparative experiment, we show that some of these tools enable to break the dilemma between creativity and robustness. Focusing on the design gap, a sample of 6 industrial designers was asked to design from a handmade rough sketch a 3D-digital object integrated in a CAD software suite. We compare the performance in term of gain or loss of originality and robustness (measured by 5 independent experts) between the uses of two representative digital design tools. It appears that the use of one of the software significantly increased simultaneously to Generativeness and Robustness of a design. It confirms that it is possible to ground creativity on constraint and show the possibility of new design processes characterized by their capacity to avoid loss in Originality and to improve what we call an "acquired creativity" all along the design process.

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independent experts) between the uses of two representative digital design tools. It appears that the use of one of the software significantly increased simultaneously to Generativeness and Robustness of a design. It confirms that it is possible to ground creativity on constraint and show the possibility of new design processes characterized by their capacity to avoid loss in Originality and to improve what we call an "acquired creativity" all along the design process.

'What is not **constrained** is not **creative**.' - Philip Johnson-Laird

Introduction

A great number of studies tend to show that industrial design is key to trigger, foster and sustain innovation (Olson, 1998) (Verganti, 2006) (Verganti, 2008). These professionals, whose work activity consists notably in "transforming a set of product requirements into a configuration of materials, elements and components" (Gemser & Leenders, 2001) have great capabilities in making "products that customers love" (Cagan, 2008) and their integration leads most of the time to a measurable performance of the firms where they work (Berkowitz, 1987) (Tushman, Anderson, & O'Reilly, 1997). Driven by these assessments, companies are trying to integrate the competencies of Industrial Designers (ID).

However, due to their unique creative and innovative capacities, these professionals are hard to fit into industrial environments. The whole challenge for firms is to provide ID enough freedom of acting to preserve their specificities, while guarantying that their work can be compatible and assimilated by the industrial design process. Can this apparent direct trade-off between creativity and constraints be solved? *In other words, can very creative professionals be* *integrated in an industrial design process without damaging or restraining their specific competencies?*

We can find in the literature different approaches and advices for the combination of creativity and the management of industrial constraints in design (such as fabrication, costs, environmental issues…). However, the best timing for integrating and exploiting the innovative potential during the New Development Process (NPD) is still debated:

For some researchers, fostering the creativity at the beginning of the design is a necessity. This analysis, which has been popularized at first by scientists working mostly on the car design process (Fujimoto, 2007) is now proposed by publications revolving around the Fuzzy Front-end approach for NPD (Khurana & Rosenthal, 1997) (Reid & de Brentani, 2004). The conformity of the design to industrial constrains seems reachable only once the creative potential being fully exploited and consumed. In this scheme a very strong creativity at the beginning of the design process appears to be the best guaranty for a maximum number of Degree Of Freedom (DOF) which won't be consumed until the very end of design (Karniel & Reich, 2011).

On the other hand, a different community introduces the design process as a succession of iterative steps which all require the capacity to challenge previous choices, to continuously "reframe the problem" with creativity. Donald Schön (Schön, 1984) (Schön, 1990) was one of the first to consider design as more than a problem solving activity. The management of constraints during the process is therefore coupled to creativity and originality. Constraints can trigger innovation while creativity could solve insurmountable technical issues. As an entry for new techniques, methods or even materials, the potential of innovation helps the progress of design and the refinement of product definition. Moreover it has been shown that recent Design

Theories tend to support a dual improvement in Robustness and Generativeness, as if these two terms could be interwoven in design processes (Le Masson, Hatchuel, & Weil, 2011).

Hence a research gap: are these two values inherently evolving in opposite directions during NPD or is it possible to have them grow simultaneously during NPD?

To go one step ahead on this complicated research question, we favored a tool-centric, experiment-based approach. The digital design tools are the dominant ID's means of action and therefore can provide vivid evidences of their effects over concepts properties. They are in a permanent fever of excitement. Because software editors use them to emerge from competition, novelties which are often released come with strong technical innovations and eye candy interfaces. Then, because these software provide a good entry door for the integration of ID into industrial companies they found large numbers of clients. This means a lot of users and a large pool of potential experiments. Last but not least, they have the very useful capacity to enhance the properties of an undersign product and this effect is moreover visible when referring to the formal and aesthetics ones.

We focus on the use of new software tools by ID analyzed in a comparative experiment. We decided to compare the capacities of two different digital design tools to integrate ID inside industrial environments and their effects on creativity. Both tools are used to generate 3D models and belong to the same design suite. The first one can be considered as an archetype of CAD Tools, where shapes are generated through process operations (extrusions,…), the second one relies more on the paradigm of clay deformation but still in the same environment. We will assess the respective impact of the use of these two tools on the Robustness and Generativeness of concepts during the “Design-Gap”.

We first present the theoretical background that leads to our research hypotheses. We then detail our experimental plan with a presentation of our experimental logic, the variables and the measures used in this study. This is followed by sections in which the actual analysis of the performances of the tool, the discussion of the results and the conclusions from this article are presented.

Motivations, Theoretical Background and Hypothesis

How to exploit the creative potential of ID without damaging it in an industrial context barded with constraints? These two sides, pillars of the design process, are seen as a Trade-Off (TO) for one field of the literature (one being obtain at the sacrifice of the other) and at the contrary for another field, in a strong interdependency state, and in Simultaneous-Solve (SS) position (one fosters and nourishes the other).

A divided literature about creativity and management of industrial constraints relationship.

<u>TO vision between creativity and industrial constraints</u>

For some researchers, fostering the creativity at the beginning of the design is a necessity. This analysis has been popularized at first by scientists working mostly on the car design process (Midler, 1995) (Fujimoto, 2007).

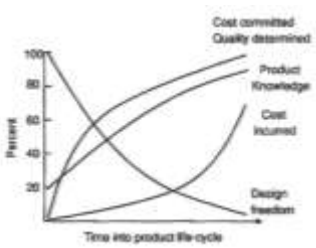

Figure 1: Product knowledge, and design freedom vs. time (Karniel & Reich, 2011).

(Karniel & Reich, 2011) Illustrate in Figure 1 the same tendency, based on the work of (Ullman, 2003). When conducting a new design, there is a progressive TO between the Degree Of Freedom (DOF) of the project (qualified also at the remaining possibilities of action) and the knowledge designers have about it. The DOF are consistent with the creative potential of the design. They are directly linked to the various ways of exploration or possibilities which have been preserved for innovation and can be used for solving the encountered issues. They are consumed as a capital while the design process progresses.

This analysis has been emphasized by publications revolving around the Fuzzy Front-End (FFE) approach for New Product Development (NPD). (Khurana & Rosenthal, 1997), who introduced the locution, note: « (…) uncertainty at the Fuzzy front end is greatest for discontinuous innovation ». FFE requires also a maximal creativity phase at the beginning of the design process. It should be free from constraints so the most extended range of solution can be considered according to (Reid & de Brentani, 2004). These recommendations are supposed to promote ulterior convergence towards a successful design because all the unpredicted upcoming issues have been previously anticipated by the preservation of a maximum number of DOF. Answering both to industrial constraints and being creative appears in this frame as two opposite values, the first one being reachable only once the potential of the second being fully exploited and done.

As a conclusion, we will classify this scheme as a TO vision between management of industrial constraints and creativity**.**

Symbiotic and Simultaneous-Solve vision

Aside to this antagonist vision, a different community introduces the design process as a succession of iterative steps which all require the capacity to challenge previous choices, to continuously "reframe the problem" with creativity. Donald Schön (Schön, 1984) (Schön, 1990) was one of the first to consider design being more than a problem solving activity. "In real world practice, problems do not present themselves to the practitioner as given. They must be constructed from the materials of problem situations which are puzzling, troubling, and uncertain", "Each move is a local experiment that contributes to the global experiment of reframing the problem", the management of constraints during the process is therefore coupled to creativity and originality.

This analysis is shared and widely spread into research communities which recommend putting creativity phases all along design process (Couger, 1990) and is illustrated in Figure 2.

Figure 2: Creative problem solving model (Couger, 1995)

Some researchers, such as (Buijs, 2003), even use the expression of "circular chaos" for the qualification of the Design process rather than "linear logic". These recommendations apply independently of the media used for conveying it, from manual materials to CAD models (Marakas & Elam, 1997).

In his book, Thomke (Thomke, 2002) indicated that any given solution or finding must be immediately assessed and tested in order to explore its alternatives and preserve some room for innovation, during the whole design process. This repetitive method of instantaneous evaluation of each proposition can be executed with the help of new tools. He gives a speaking example about the CAD case, and its auto-experimentation capacity: « Because they received immediate feedback on the technical merit of their ideas, designers were emboldened for experiment and even more – for example, removing weight from individual parts.”.

Insights form design theories

This symbiotic approach is also shared by the academic community working on design theories. These theories tend to establish design propositions which could be evaluated upon two criteria according to (Hatchuel, Le Masson, Reich, & Weil, 2011) :

i) Their *Generativeness*, i.e. their ability to produce design proposals that are different from existing solutions and design standards;

ii) Their *Robustness*, i.e. their ability to produce designs that resist to variations of context.

They form altogether a consistent body of knowledge that has aimed to increase the Generativeness of design without losing its Robustness.

In the perspective of our paper, Generativeness is the corresponding value to creativity and originality of design, while Robustness is similar to what we called the management of industrial constraints. In some of the most well-known design theories such as General Design Theory (Yoshikawa & Uehara, 1985), Axiomatic Design (Suh, 1990) or Concept-Knowledge (Hatchuel & Weil, 2002) recommendations to practitioners are to take in account and to manage simultaneously during the whole design process these two dimensions in order to reach faster the product with the wanted properties.

For a better definition of the mainly used ID tools we also performed a literature review by pointing on two archetypal types and coined their tendencies:

Strong tropism of the design tools

<u>Tools providing high Generativeness and poor Robustness</u>

This category of tools offers high capacities for conceptual explorations, with no or little cost, but they are not integrated inside the industrial process, as their productions can be lost during the process. They derivate from the sketch and tend to share most of its properties and qualities: quick, timely and inexpensive. Sketch is obviously one of them but we could also consider clay modeling of patch working belonging to this category due to their properties and uses during the early phases of the process. They aim to provide a maximum of creativity to their users and are often used to present a set of possibilities at the beginning of design process Invalid source specified.. These tools are also very well suited for the introduction of rapidly formalized concepts and are considered as an explorative method which makes them very consistent with the Generativeness of the process. Sketching activity makes mental models easy to represent and manipulate and its simplicity gives the designers a good potential of reinterpretation and discussion with himself or others (Remko, 2002) and can also be used as a communication tool for conveying ideas or concepts from ID to other designers such as engineers or managers as pointed by Invalid source specified..

Beside the traditional "sketching" tools, new numerical design interfaces which mimic them also appeared (Bae, Balakrishnan, & Singh, 2008). They have the same advantages like a good support for creativity (Barone, 2004) but also share their flaws. They provide poor integration, mainly because the generated 3D models are not compatible with CAD industrial environments and they hardly participate to the Robustness of the design. We call them "Digital Artistic" tools and they will not be assessed in this paper as they can't be qualified as integrated.

Therefore this global category of tools (traditional and digital) trades-off Robustness for maximal Generativeness.

<u>Tools providing high Robustness and poor Generativeness</u>

As the numerical industrial tools progressively imposed themselves into the design environments, CAD tools gave ID the opportunity to use the same means of action as the engineers. But while they provide a very good integration, they have the unwanted tendency to sacrifice creativity by restraining the possibilities of conceptual explorations. This category of tools tends to bound and simplifies too much original concepts by integrating them very soon into the process and its technical and legal constraints.

This can be explained because these tools where at first designed for engineers (Henderson, 1999) and their first ambition was to increase the quality and Robustness of designs by limiting the most costly iterations between different media (such as blueprints, prototypes and 3D models). Like the sketches, CAD tools prove to be very good coordination and collaborative tools with the superior advantage to provide a non ambiguous representation of products (Thomke, 2002). They can generate « boundary-objects » which have good capabilities for transferring, translating and transforming knowledge across (syntactic, semantic and pragmatic) boundaries (Carlile, 2002) (Carlile, 2004) between ID but also with the other participants to design (managers, engineers, marketing…). But along with these qualities CAD tools has several drawbacks on the creativity of its users: circumscribed thinking (limitation of modeling possibilities), premature fixation (summons detail modeling too early) and bounded ideation (Robertson, Walther, & Radcliffe, 2007). ID also complain about the lack of control and spontaneity of the tool: they feel like their intuitive design qualities are transformed into virtual data processing (Wendrich & Tragter, 2009). Computers compartmentalize, break activities into isolated steps, and focus on rigid logic and literal meanings (Diffrient, 1994) and when using this type of tools they also tend to focus on geometrical aspects and occult meaning creation (Verganti, 2008), one of their essential competency. We call them “Shape Construction” tools.

This type of tools trades-off Generativeness for maximal Robustness.

As a conclusion we can say that the first generation of digital tools consisted in a restricted choice of tools to ID: on one hand very creative tools oriented for the beginning of the design but not suited for industrial requirements as they trade-off robustness for generativeness. On the other, very well integrated tools managing collaboration and industrial constraints while bounding (when not obliterating) ideation which trade-off generativeness for robustness. This literature review of the logics of design tools for ID seems to indicate a strong tropism upon the TO vision between Robustness and Generativeness.

We will first assess the properties of the “Shape Construction” tools and check if the results are consistent with the literature.

Still there is today a new generation of digital tools that are integrated in the product design software suites (hence as Robust as the “Shape Construction” tools) and try to keep the way a designer naturally tends to shape objects, by following the logic of clay-modeling or sketching in 3D environments. All these properties inside an industrial environment are a major breakthrough, but will it keep it promises? It seems that this new generation of tools tends to increase R and G and some of them have already successfully been introduced on the market and used in industrial environments. We will call them “Shape Deformation” tools.

In this perspective, how can the performance of “Shape Deformation” tools differ from their predecessors and enable a simultaneous increase of Robustness and Generativeness of the design?

1.3 Hypothesis Formulation

We therefore formulate our working hypothesis.

- **H1**: When ID use “Shape Construction” tools they are able to improve the **Robustness** of concepts but at the cost of **Generativeness**.

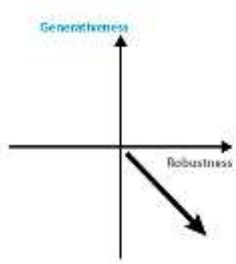

Figure 3: H1 mapped in the Generativeness/Robustness space

- **H2**: When ID use “Shape Deformation” tools they are able to **improve** simultaneously the **Generativeness and Robustness** of concepts.

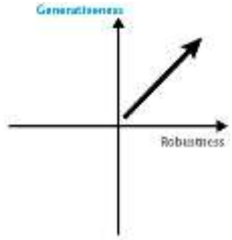

Figure 4: H2 mapped in the Generativeness/Robustness space

Experimental Method

To test our hypothesis, we conducted an experimental protocol. We wanted it to derivate from the real and practical uses of ID in design situations and aim for the interplay between their integration into industrial design process and its impact on their creativity. To analyze how these professionals conduct their work we focused over their means of action.

Choice of Design Step and Tools

We process this study during one of the most emblematic phase of the design process, the transition between traditional and numerical media sometimes called “Design-Gap” (Dorta, Perez, & Lesage, 2008). This brutal and stringent switch happens when concepts represented with traditional means (sketches, mock-ups of all kinds, prototypes …) are modeled (digitalized) on computers. This step is very stressful for software and stresses their capabilities. The ID found it extremely critical because they fear treason of their initial design intentions. At this phase the concepts become integrated into a software design suite that will support the full development to the final product. Hence after the design gap Robustness should have increased. But there is a risk that it is at the price of a loss in Generativeness.

We chose to compare two software which ID use on a daily basis to bridge the design gap. Both lead to “integrate” handmade sketches into the same software design suite. Each design tool is a so-called workshop that helps the designer to transform the handmade sketch into a digital shape as illustrated in Figure 5.

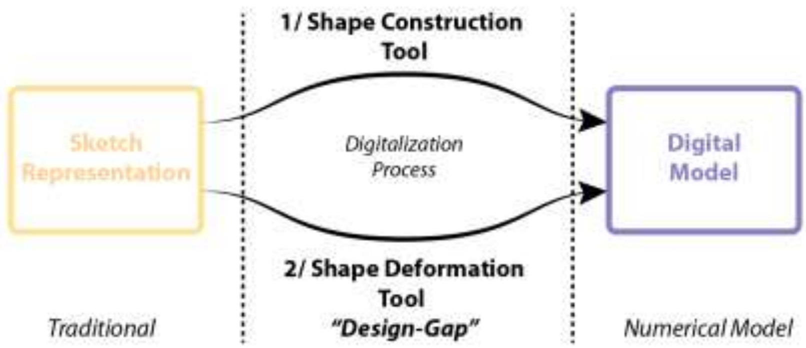

Figure 5: Managing the Design-Gap with two different digital tools

The first workshop we wanted to test is the archetypal of the CAD tools (and will be called as "Shape Construction Tool" in the following). It uses procedural commands and modeling appears as a succession of steps where the construction of blueprints (called two-dimensional (2D) sketches in the software) is followed by the use of functions (such as extrusions, revolutions or sweeps…) in iteration. It is capable of producing surfaces of very high quality (up to Class-A standard, the highest in the industry).

The second one, which will be called "Shape Deformation Tool" in this paper, is also a digital tool and shares its integration into the same design suite. This tool is fully integrated inside the global design suite which is suitable for all types of industrial designs. The generated models made inside the suite are fully compatible between its various workshops (i.e. other design tools for specific tasks). Any creative design done with the tool can be transmitted to other designers and has the capacity to integrate industrial constrains. It embeds mathematical constrains which ensure the generated shapes will have a certain standard of quality at any time (curvature continuity).

This second tool differs from "Shape Construction Tool" through one main property: its user interface is an archetypal of creative design software. The objects' manipulations are direct and provide instant feedbacks thanks to the use of a « manipulation box ». This also allows a very high degree of precision upon the creation and modification of shapes. ID can work with a lot of control and speed over the formal properties of concepts without invocating commands, functions, or even parameters. Interestingly users sometimes qualify it as a type of clay modeler.

Design Briefs

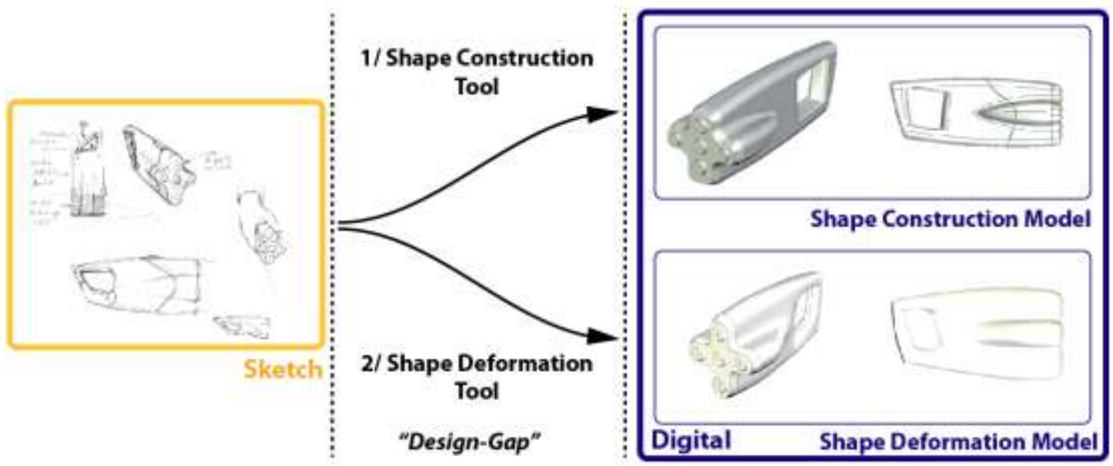

Figure 6: Materials collected before and after Design-Gap

ID usually perform the "Design-Gap" with "Shape Construction" tools because they serve as direct entry doors to the industrial world and its CAD codifications and specifications, inevitable for the upcoming manufacturing. Our goal is to assess the capabilities of a new breed of tools, namely the "Shape Deformation Tool" and to compare it with the current method, namely "Shape Construction" and see whether these new tools can verify H2. We assess their respective performances during this digitalization step (over the "Design-Gap") as illustrated in Figure 6.

We worked with six ID from a famous CAD company. They all had an ID education and worked as designers during three to twenty years with these tools or similar ones. Hence they are experimented for each of the tasks they had to fulfill: generate sketches (before the design gap); and model them in 3D with both numerical tools (bridge the design gap).

They were given design briefs, describing with precision what was expected from them.

-At first, they were asked to produce two different formal concepts of an “autonomous portative lamp” by representing them with sketch. Each of them was given full access to ideation material: pen, paper, pencils, rubber and a computer with graphical software. They had one hour time to perform their design and were free to ask any question. When they were done, their sketches were collected and scanned.

-Then they were asked to make 3D modeling of both their sketched concepts with both modeling tools, “Shape Construction Tool” and “Shape Deformation Tool”. They had one hour time for each concept modeling, two hours total. They were recorded all along. To avoid learning effects we randomized the modeling, half of ID started with “Shape Construction Tool”, the other half with “Shape Deformation Tool”.

Data and evaluation protocol

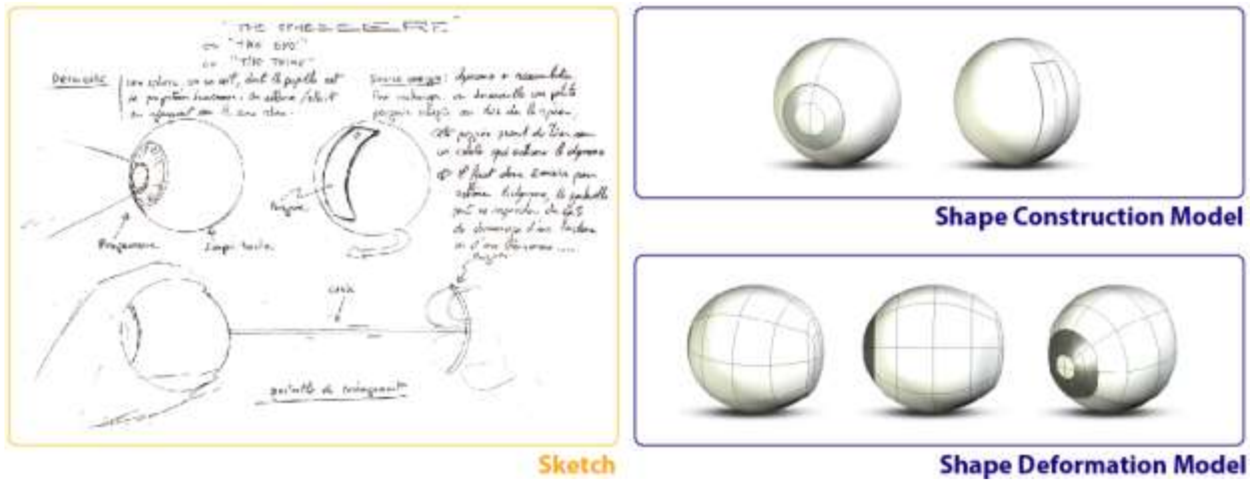

Figure 7: Representation collected for Concept 4

For each sketched concept, we obtained two sampled numerical representations, twenty-four in total. Figure 7 shows the collection of sketch and 3D models by one ID.

We assess and compare the contribution of both tools to design Robustness and Generativeness during the "Design-Gap". We measure Generativeness and Robustness by using the usual indicators Originality and Feasibility (Magnusson, 2003) (Runco & Charles, 1993). The formal Originality of the concept is consistent with the Generativeness of design. In the experiment, assessment was made on the Originality and Feasibility of a shape. A very original shape is the guarantee of a high creative potential which will be available for exploration and innovation during the whole design process. It is uncommon, surprising, atypical and can reveal new meanings. The formal Feasibility of a concept is similar to the Robustness of a design. A feasible shape will bring a simplified design with less unknown and difficulties. It exhibits refinements and detailing. It has a given quality of surface which can be rated and evaluated over mathematical and optical criteria.

We here give a graphical example of what is called surface quality. Along with the visual criteria, it is also possible to describe mathematically the quality of the shape (see Figure 8).

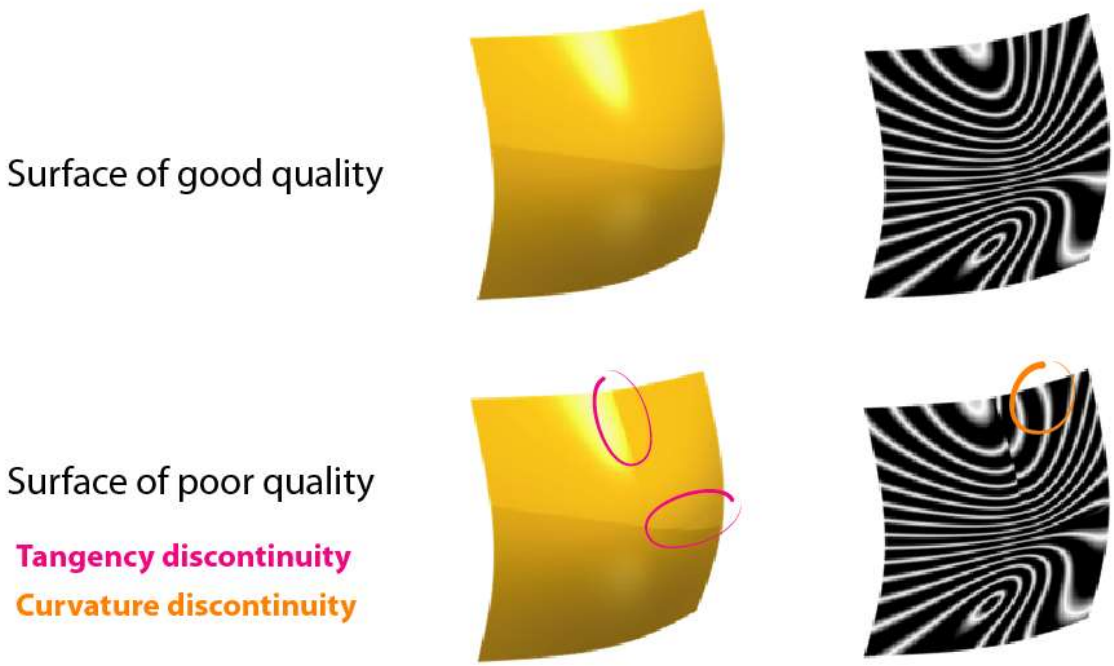

Figure 8: Evaluation of a surface quality

To evaluate Feasibility and Originality, we use an expert evaluation, "The Consensual Assessment Technique" (CAT) developed by Amabile and colleagues (Amabile, 1996). We contacted five ID experts who were in charge of evaluating the evolution of the concept's properties along Feasibility and Originality.

The five ID experts are experienced in assessing design concepts. They are used to rapidly give evaluations on projects under development and will be called "experts" in the following of this article.

Because the experts had to evaluate respective contribution of both tools to design shape Feasibility and Originality we provided them the reference sketch for each concept and its pair of digital 3D models. They rated the *progression* of Feasibility and Originality of its shape from the sketch step to the digital model by using a Likert (Likert, 1932) scale of five items. They process it twice, for the "Shape Construction" and for the "CI Tool". In each case the expert was provided simultaneously with the handmade sketch and the digitalized shape made with the support of one of the two tools (models were provided in random order and where not reckonable). He had then to evaluate the gain or loss in originality.

For both Feasibility and Originality the Likert items and their corresponding grades were: Strong decrease (-2), Decrease (2), Neutral (0), Increase (+1), and Strong increase (+2). We obtained two grades for each concept and modeling tool type, one for the Feasibility evolution, the other one for the Originality evolution of the representation's shapes, 48 in total. To assess the respective impact of "CI tool" and "Shape Construction" on concepts we calculated the mean progression for each modeled concept property by taking all five experts marks. The result is an aggregated ΔOriginality (ΔO) and a ΔFeasibility (ΔF) for each numerical concept, matching with a tool. It can be mapped on the ΔFeasibility-ΔOriginality space and provide a Design-Gap performance for a single concept (see figure 9 below)

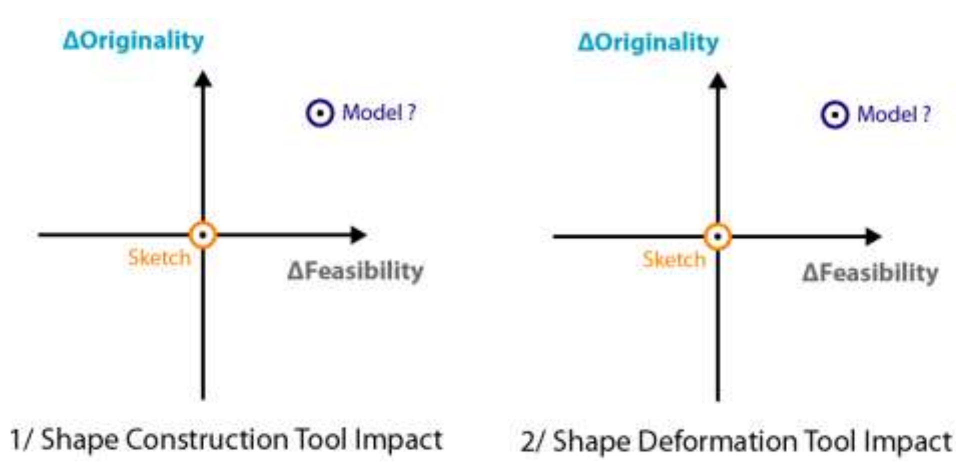

Figure 9: Evaluation of tools impacts over concepts

Results

Quantitative results

Consistently with previous we characterize the Design-Gap performance of the tools. When the experts rate a strict progression of Originality and Feasibility ($\Delta O < 0$ & $\Delta F > 0$) we call this progression a SS. For a diminution of Originality and a progression of Feasibility ($\Delta O \leq 0$ & $\Delta F \geq 0$) we categorize this as a TO. "Others" marks indicate a loss in Feasibility ($\Delta F < 0$) which could imply a gain ("Other1") or a loss ("Other2") in Originality (see Figure 10 or Figure 11 which explains how the value of the variable Design-Gap performance was affected to TO, SS and Other for both tools).

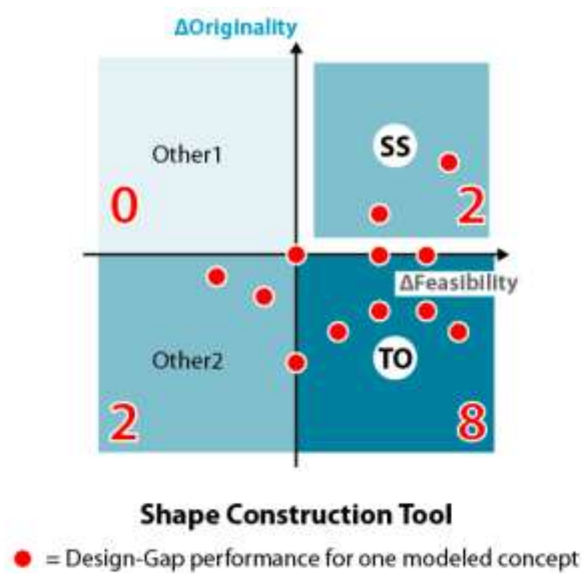

Figure 10: Mapping of the Design-Gap performance for Shape Construction Tool

H1-0 hypothesis is formulated as, the Design-Gap performance of "Shape Construction Tool" leads to a uniform distribution between the four different sectors, TO, SS, "Other1" and Other2". We test H1-0 with a χ^2 test for a two-sided 2.5% trust interval. We obtain for the χ^2 a total distance of 12 which is superior to the table distance of 9.3. We can reject on these results H1-0 and formulate a non-uniform distribution of "Design-Gap" performance for "Shape Construction Tool". We then test if there is a significant difference between the proportions of TO, SS and "others". This difference is made by TO, as can be seen by looking at the confidence intervals on a two-sided 5% trust interval: with 8 out of 12 concepts the frequency of TO is 66.7% ± 22.3% while for SS the frequency is 13.7% ± 17.6%. TO frequency is hence significantly superior to SS frequency (and "Other1" and "Other2"). Therefore we can conclude positively with **H1: when ID use "Shape Construction Tool", they are able to improve the formal Feasibility of concepts but at the cost of formal Originality.**

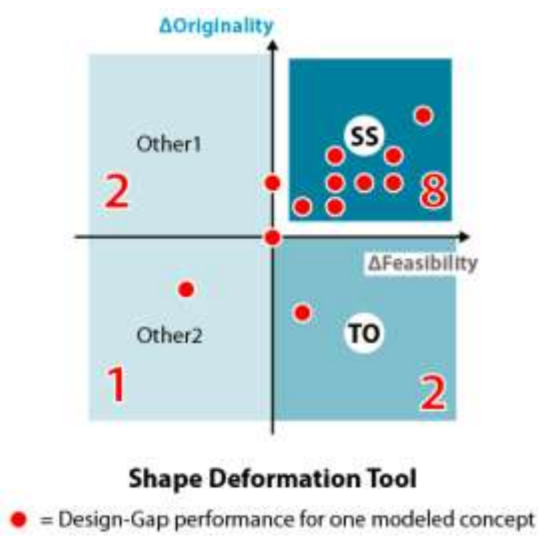

Figure 11: Mapping of the Design-Gap performance for Shape Deformation Tool

H2-0 hypothesis is formulated as, the Design-Gap performance of "Shape Deformation Tool" leads to a uniform distribution between the four different sectors, TO, SS, "Other1" and Other2". We test H2-0 with a χ^2 test for a two-sided 2.5% trust interval. We obtain for the χ^2 a total distance of 11.3 which is superior to the table distance of 9.3. We can reject on these results H2-0 and formulate a non-uniform distribution of "Design-Gap" performance for "Shape Deformation Tool". We then test if there is a significant difference between the proportions of TO, SS and "others". This difference is made by SS, as can be seen by looking at the confidence intervals on a two-sided 5% trust interval: with 8 out of 12 concepts the frequency of SS is 66.7% ± 22.3%.

For TO the frequency is 13.7% ± 17.6% while for SS frequency is hence significantly superior to TO frequency (and "Other1" and "Other2"). Therefore we can conclude positively with **H2: when ID use "Shape Deformation Tool", they are able to improve simultaneously the formal Feasibility and Originality of concepts.**

Qualitative results

Besides the quantitative results we obtained, we found interesting to perform a qualitative analysis of the formal evolutions the concepts went through. It seems that there could be at least two different kinds of formal originalities revealed in our study. The first one would not be specific and depends of the global shape of the concept. It is what the experts assessed in our experiment by using criteria such as:

-The shape seems really hard to produce.

-The cultural context is not felt.

-The shape seems iconic.

-the shape is very exact and simple.

We called the second one "*Acquired Originality*" and found it to be as much relevant in our case. This "*Acquired Originality*" corresponds to an Originality which embeds the Feasibility of the concept. "Shape Deformation Tool" proposes infinite possibilities for the generation of shapes as long as they comply with the internal rules of its mathematical model. In this frame, every original shape will at least respect some pre-established rules of surface quality. Hence the SW design tool makes that any object in the workshop is always at the A-level of optical quality. The software warranties constantly this quality criterion, hence enabling a good Feasibility level. Interestingly enough some designers will play with the rule. They explore the space of possible shapes to design shapes that are optically correct and still are original and unexpected under this level of optical quality. Hence they also gain in originality.

But this originality is *based on* the validated criteria of optical criteria. Hence one can considered that the originality is validated too! The two dimensions, F and O, are now coupled together in a positive way – if one wants to keep the optical quality, then one will keep the shape and the originality associate to it. Conversely, reducing the shape originality would not increase robustness but would decrease the optical quality and hence decrease robustness. Freezing the degree of freedom of the shape increases robustness *and increases originality*. Hence one can speak of "robust originality" or "acquired originality".

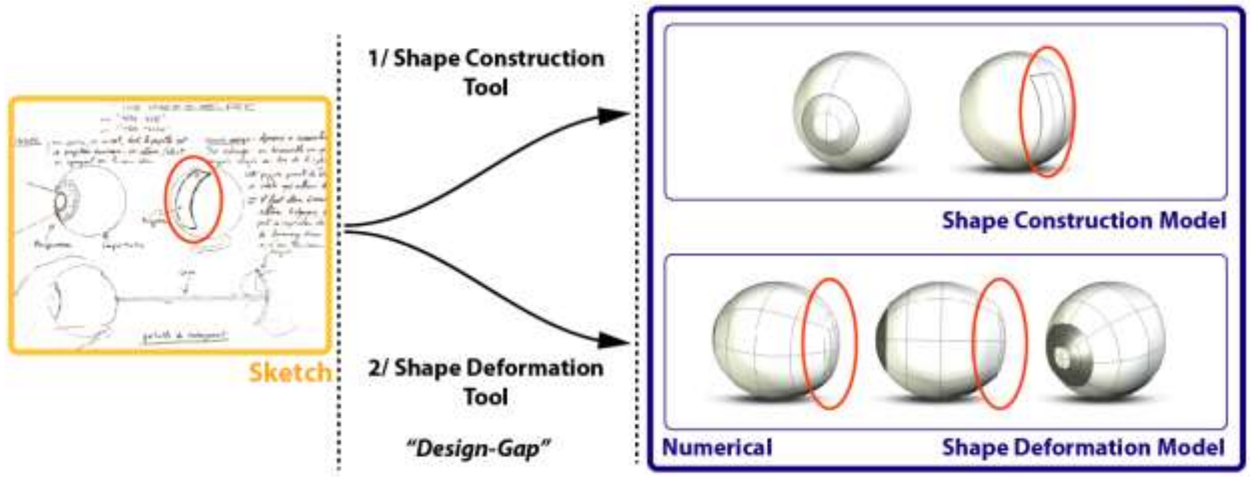

Figure 12: Apparition of a new shape attribute

Acquired Originality can be precisely seen in the example in Figure 12. We can note the apparition of a new shape attribute and a slight modification of the shape. The ovoid has a surface quality provided by the "Shape Deformation Tool" mathematical model but yet it is more surprising and original than the almost-perfect-sphere modeled above. The designer was able to go out of the sphere while keeping optical quality. He *added* a facet hat was not on the original sketch and was not usually associated to A-level optical quality (A-level optical quality favors strong surface continuities whereas facets tend to introduce discontinuities). The constrain led to originality and the originality is jointly acquired with the robustness.

The *Acquired Originality* of the shape is explained by being both "*qualitative*" AND "*original*". The quality constrain has become a trigger of the creativity. This finding may appear at first at surprising but the literature on multiple domains is full of creativity increased by constraints as brilliantly illustrated by G. K. Chesterton: *"Art consists of limitation. The most beautiful part of every picture is the frame."*

Discussion & Further Researches

Limitations

Due to the exploratory nature of this experiment, they are some limitations to our findings. First restriction concerns the scarce number of representations, concepts and ID used in his experiment. This could have some serious misleading effects, even if our results seem to indicate a global trend that back up our findings. The design of experiment (comparative empirical study that led to paired samples) helped to get very good confidence level despite the small sample size.

The shape *Originality* and *Feasibility* offered by the modeling tools could be correlated to the type of concept, in our case, "autonomous portative lamp". We should try our experiment with concepts depicting various products and from various industries.

Side Findings & Further Developments

Sketching is not the only representation used for concept exploration by ID. They also often manipulate clay models, 3D digital models made with "3D Artist" tools, prototypes or even photomontages. It should be very useful to measure the progression of shape Originality and Feasibility when transitioning from these media to 3D industrial models.

The study may also be extended to test another configuration of the industrial design process. ID often do not produce themselves every representation of the concept they are working on, even in the first stages of the design process. They are sometimes helped by modelers who are in charge of modeling in a 3D CAD environment their propositions. It could be very interesting to perform the same experiment, with only a few concepts produced by a same experienced ID and to evaluate how different modelers with both “Shape Construction” and “Shape Deformation Tool” will perform the “Design-Gap”.

In a future work we propose to make variation of the evaluation methods of the experts by providing them efficient 3D viewers we prototyped, to get a different perception of the 3D models provided.

We also noted that the time ID took for modeling the different representation of their concept was highly correlated to the tool they used. Time taken when using “Shape Construction” is about 40% higher than when using “Shape Deformation Tool”. Further than their respective contribution to the design of the products, it could also very meaningful to assess their respective effectiveness in another experiment.

We also plan to obtain a better knowledge about the *Acquired Originality* and try to model it, and how it could be obtained in different contexts.

Conclusion & Managerial Implications

The results of this experiment show several findings and confirm results of the literature. The dominant industrial tools, software similar to “Shape Construction”, have the powerful capacity to dramatically improve the Robustness of a design but at the cost of its Generativeness. On the other hand, the “Shape Deformation Tool” provides better management and preservation of the Generativeness while offering a quite similar improvement of Robustness. Even if further researches could be required to confirm these findings, and moreover its capacity to provide no TO design processes, it is a very important lead for the pursuit of these insights.

Managerial Implications

With tools such as “Shape Deformation Tool” and their capacity to perform SS during design processes the ID could be able to manage the Generativeness and Robustness of their design to best fit the needs of their company at any given moment. With such capabilities the design process could be revised and its versatility and robustness dramatically improved like illustrated in Figure 13.

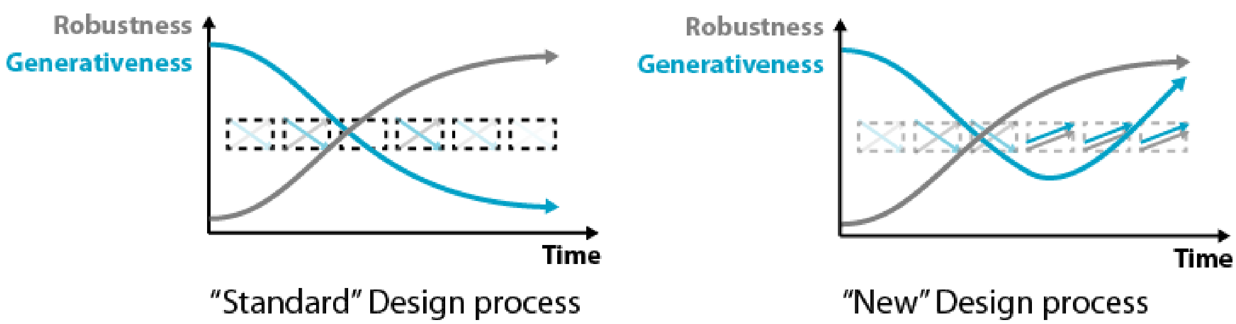

Figure 13: “Standard” and “New” design process profile

This experiment also suggest that with tools able to enhance simultaneously the Robustness and Generativeness of the concepts new design process could be imagined and applied in the industry. They would have the property to differ from trade-off ones and offer designers the capacity to inject Robustness or Generativeness when needed.

Further Researches

We could use this method of evaluation based on Robustness and Generativeness for different digital design tools, for instance one which aims at redacting the requirements of the concepts or even its function and logical properties.

We could also use our findings to select some interesting properties of the "Shape Deformation Tool" and to inject them inside other digital design tools to make their user simultaneously more creative and integrated.

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