ANALYZING THE GENERATIVE EFFECTS OF SKETCHES WITH DESIGN THEORY: SKETCHING TO FOSTER KNOWLEDGE REORDERING

Brun, Juliette; Le Masson, Pascal; Weil, Benoit
MinesParistech - PSL Research University, France

Abstract

Sketching constitutes an essential work tool for designers. On the first hand, sketches allow to externalize ideas, being then very economic cognitively. If they help to process information very quickly, sketches are also an integral part of the thinking process, without which the designer would not be able to access originality and novelty: in particular, the fact that some sketches bring new insights to the designer seems to play an important role for the emergence of ideas. Our research project aims to clarify how architects use sketches to reach generative effects by analyzing their design strategies and the way their drawings can support these strategies. We especially focus on the role of knowledge in comparison to concepts. Three sequences of sketches were analyzed thanks to the C-K design theory: two sequences of thinking sketches and one sequence of talking sketches. We show that most drawings refer to both knowledge and concepts. Moreover, our study reveals that architects carry out through sketching an important work of knowledge structuration. Indeed, generative effects often result from the introduction of new knowledge reordering the initial knowledge basis.

Keywords: Sketching, Design theory, Design methodology, Knowledge reordering, Early design phases

Contact:
Juliette Brun
MinesParistech - PSL Research University
Centre de Gestion Scientifique
France
juliette.brun@mines-paristech.fr

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1 INTRODUCTION

Looking around an architects' office, sketches can be found everywhere: notebooks are often mostly filled with sketches and large drawings fixed on the walls present the final deliverable of architectural projects. Sketching constitutes indeed an essential work tool for designers (Fergusson, 1992): on the first hand, it allows to externalize ideas and information, therefore enhancing memory and thought (Goel, 1995; Suwa and Tversky, 1997; Tversky, 1999). On the other hand, sketching offers an instant feedback to the designer, who can very quickly evaluate and modify his ideas (Schön and Wiggins, 1992; Goldschmidt, 2003).
Some studies tend to show that drawings not only allow processing information, they are also a key ingredient to access originality and novelty. In fact, new ideas come not only from the designer's mind but also from sketches themselves. Sketching brings new information to the designer, which promotes idea generation (Schön, 1983; Suwa, Tversky, Gero and Purcell, 2001). Allowing to read generic qualities through particular forms and to transform generic rules into specific representations, drawings appear essential for the emergence of ideas (Goldschmidt, 1991). Moreover, sketching can foster reinterpretation during the individual thinking, which enhances the creative process (Van der Lugt, 2000, 2002, 2005). However, not every sketch is able to enhance the design process (McGown, Green and Rogers, 1998, 2000).
Our research project aims to clarify how architects use sketches to reach generative effects i.e. effects enhancing variety or originality of their explorations. Especially, we try to understand the way sketching help architects to produce completely new things. To do so, we analyze design strategies used by architects and the way sketches support these design strategies (Hatchuel, Le Masson and Weil, 2004). We especially focus on the role of knowledge in comparison to concepts. We will first introduce a brief literature about sketching, its impacts in early design and its relation to the design strategies followed by the architect (Part 2). We will then present an analysis led thanks to the C-K design theory (Hatchuel and Weil, 2003, 2009) on three sequences of sketches (Part 3 and 4). In conclusion, these results will be discussed and we will open further lines of development (Part 5).

2 UNDERSTANDING SKETCHING AND ITS ROLE IN EARLY DESIGN

2.1 Sketching: An essential work tool for designers

2.1.1 Sketches at various stages of the design process

Fergusson (1992) emphasizes the generative effects of sketches, explaining that drawings play a major role in the emergence of technological breakthroughs. He highlights the necessity of non-verbal thought for engineering and shows that drawings intervene at various stages of the design process. Fergusson distinguishes three categories of sketches: "Thinking sketches", made by an engineer looking for new ideas, "talking sketches", made when two engineers communicate, and "prescriptive sketches", meant to please and convince people outside of the design process. Thinking sketches are often the fuzzier drawings, and prescriptive sketches, the more beautiful. Even if these categories are named after properties of sketches – thinking, talking and prescriptive -, the different categories are in fact based on stakeholders: the designer alone for the thinking sketch, two designers talking for the talking sketch and a designer with people outside of the design process for the prescriptive sketch. Then, a talking sketch in the sense of Fergusson can be used to talk, but also to think or to convince. In the same way, idea generation is not to be associated only with thinking sketches but can also occur while working with talking or prescriptive sketches.
If the generative power of drawings justifies their involvement at various stages of the design process, however, the nature and the reasons of this generativity remain unclear.

2.1.2 Quick information processing

Some studies show that sketching can enhance the thinking process by facilitating information processing. Indeed, if sketches are so essential for designers, this is because they can be seen as cognitive crutches supporting the design reasoning. First, they allow an externalization of the designer's ideas (Tversky, 1999). However, drawings are not a presentation of a given reality but a representation of this reality: indeed, they differ in the form and content from the object they represent (Suwa and Tversky, 1997). Moreover, the architect chooses which elements to put in his sketch: he

can include important information given the explored subject or eliminate irrelevant information. Sketching thus constitutes an important cognitive tool. In particular, it improves memory and thought (Goel, 1995) and allows processing very quickly visual and spatial information. Schön and Wiggins (1992) also point out that sketching offers an instant feedback, very economic cognitively.
This quick information processing then enhances the design process and can increase the fluidity and variety of the exploration. However, the fact that sketching increases exploration speed does not involve higher originality. To explain how sketches may enhance the production of an original object, stronger generative effects should be involved.

2.2 Towards generative effects increasing originality

2.2.1 Sketching enhances reinterpretation

If the Fergusson's categories are based on stakeholders, the eponymous functions of these categories – thinking, talking, prescriptive – constitute actual functions of drawings within the design process. Van der Lugt (2000, 2002, 2005) studied how the use of sketches to represent concepts impacts idea generation meetings. He identifies three potential roles of drawing during idea generation: sketching could provide a support for reinterpretation during the individual thinking process (in relation to a "thinking" function) or could even support reinterpretation of someone else's drawings (in relation to a "talking" function). At last, sketching could give a better access to earlier ideas, fulfilling a "storing" function. Van der Lugt compares two processes: brainstorming and brainsketching, where participants record ideas with sketches instead of post-it notes. During idea generation meetings with industrial designers, it appears that brainstorming generates significantly more ideas, whereas brainsketching provides a better access to earlier ideas and helps supporting reinterpretation in the individual thinking process. This reinterpretation enhances the creative process because it corresponds to new ways of seeing a drawn representation and provides new directions for idea generation (Purcell and Gero, 1998). Then, sketching does not only help to process and organize information: thanks to its role in reinterpretation, it also brings new insights to the designer.

2.2.2 Bringing new insights to the designer

In a design-oriented context, sketching brings new information to the designer, which promotes idea generation (Schön, 1983; Suwa, Tversky, Gero and Purcell, 2001). Indeed, freehand sketches are often dense and ambiguous, which allows the designer to see new things - new information and new ideas - in his drawings (Goel, 1995). That's why Goldschmidt (2003) mentions a dialogue between the architect and his sketches. The designer reads new information and can thus enrich his reflection in response to this new information. In the case of sequences of sketches, invisible information is also present on the paper between the drawings. For example, the different sketches can be related to one another: even if this relation is not visible on the paper, it constitutes information included in the sequence of sketches. Moreover, Goldschmidt (1991) clarifies this ability of sketches to bring new information by pointing out the role of depiction in idea generation: during "thinking loud" sessions, architects were asked to express their thoughts while drawing and each sequence of statements was analyzed. It appears that two types of statements could be distinguished: "seeing that" propositions and "seeing as" propositions. The designer is "seeing as" when he uses figural argumentation and "seeing that" when he uses non-figural argumentation. For example, he sees his drawing "as" a puzzle and "that" this is a good way to solve the problem. Moreover, an alternation appears between "seeing as" and "seeing that" propositions. The role of "seeing as" is to enable visual displays that help the designer to translate descriptive propositional information into depiction. Allowing translating generic qualities into particular forms and generic rules into specific representations, depiction plays indeed an essential role in idea generation. Fish and Scrivener (1990) had already seen that depictive information could be used to extract original descriptive information, and so, provide new insights for the designer.
Then, sketching can enhance the design process by bringing new information and new ideas to the designer, which increases the originality of his exploration. However, these generative effects of sketching are not systematic, not even of the same nature: indeed, it is not enough to sketch to enhance the creative process. In particular, a study of McGown, Green and Rogers (1998, 2000) shows that the design strategy used by the designer plays a key role in the efficiency of the sketching activity.

2.3 Modeling the design strategy to identify generative effects of sketching

2.3.1 How the designer's strategy impacts design quality

McGown, Green and Rogers (1998, 2000) studied the relation between the designer's strategy to reach novelty and the quality of his exploration. They analyzed industrial designer's sketches, focusing on operations carried out to switch from one sketch to the other. They used the distinction between lateral transformations and vertical transformations (Goel, 1995): lateral transformations consist in movements from one idea to a different idea, whereas vertical transformations are movements from one idea to a more detailed version of the same idea. The study shows that not every sketched exploration led to generative effects i.e. variety and originality. On the contrary, a quality and completed design is the result of design strategies that balance both lateral and vertical transformations. Moreover, lateral transformations often occur thanks to the ambiguity of sketches, since ambiguity provides new insights to the designer (Goel, 1995).

Then, if the designer wishes to achieve both variety and originality, his sketches should bring new insights, not just once, but several times, at various stages of the design process. It also appears that design strategies can be less or more efficient and may be less or more controlled. Here, the design strategy is identified by a succession of lateral and vertical transformations, but design strategies can also be identified in several ways.

2.3.2 Several ways to identify design strategies

A design strategy corresponds to a way to explore an initial concept. In creativity, divergent thinking and convergent thinking can be distinguished to identify the type of design reasoning involved in the exploration: convergent thinking consists in giving a single answer to a particular problem, and divergent thinking, consists in giving a various panel of answers. Finding maximum alternative uses for an object – for instance, a brick or a toothbrush – constitutes an example of divergent thinking exercise (Guilford, 1950, 1967; Torrance 1962, 1966). In early design, divergent thinking will be encouraged to obtain a various panel of original concepts, whereas convergent thinking will be used to evaluate and select ideas. The design strategy can thus be highlighted by the alternation between divergent thinking and convergent thinking processes. Moreover, the quality of individual divergent thinking can be assessed by the fluidity, variety and originality of ideas (Guilford, 1950, 1967; Torrance 1962, 1966). Other metrics such as ideas novelty and quality (Shah, Smith and Vargas-Hernandez, 2003) can also be developed to help measuring ideation effectiveness.

To foster generative effects, exploring various concepts with divergent thinking seems thus to be an appropriate strategy. However, the exploration of knowledge is also important to further generative effects. Indeed, Cropley (2006) argues that exploring knowledge with convergent thinking is necessary to produce new objects: divergent thinking needs a knowledge basis to operate and well-structured knowledge allows exploring variety in a relevant way. Highlighting the interaction between concepts and knowledge seems therefore important to understand the generative effects of sketches.

2.3.3 Modeling concepts and knowledge exploration

In early design, exploration of concepts and exploration of knowledge constantly work together. For instance, the proposition "a building as a puzzle" doesn't make sense itself: it is a concept (Hatchuel and Weil, 2003). Some knowledge, propositions with a logical status - either true or false - will be needed in order to know what such a building could be in practice. The initial concept could then be specified with other sub-concepts. The designer can choose to explore very different concepts or to focus on one particular path. In both cases, additional knowledge will be needed to continue exploring the original topic until a completed design appears. Modeling the alternation between knowledge and concepts allows differentiating several types of design strategies: in particular, we can distinguish "breadth-first" strategies, which consist in exploring various paths from the original concept, and "depth-first strategies", which consist in focusing on a single path (Hatchuel, Le Masson and Weil, 2004). The first strategy allows reaching originality but is very costly in terms of knowledge. The second strategy does not lead to a high level of originality but allows working with minimum knowledge: the exploration consists in finding new value for this knowledge. Especially, a depth-first strategy leads to a reordering of existing knowledge to develop new concepts.

Even with this K-reordering, breadth-first and depth-first strategies often consist in playing mostly with concepts rather than knowledge: these strategies can be described as Concept-oriented strategies.

It also exists Knowledge-oriented strategies: Le Masson, Hatchuel and Weil (2013) have pointed out the generative power of knowledge reorganization: reordering knowledge and working mainly in terms of knowledge can lead to the production of new objects without exploring alternative concepts.

2.3.4 Studying the generative effects of sketching within the design process

Then, modeling the alternation between concepts and knowledge allows to better understand the design strategy followed by the designer and the generative effects involved. Moreover, we can expect that sketches play a key role in this concepts/knowledge alternation since they bring new insights that could be as well concepts as knowledge. In our study, we then focus more precisely on the way sketching supports design strategies, i.e., the relation between the new insights provided by the drawings and the design strategy used to reach originality and novelty. We especially wonder if architects play mostly with ideas and concepts, as might be expected, and we will focus on the role of knowledge in comparison to concepts.

3 METHODOLOGY: ANALYZING SKETCHES WITH C-K THEORY

3.1 Selected sketches

The study was led on three sequences of architectural drawings. Sketches were selected in an architecture agency that mixes both architects and engineers. The agency is well known in the world of architecture for its breakthrough solutions, especially in façades design. It was notably involved in the design of the new Fondation Louis Vuitton in Paris and has developed an innovation approach around freehand sketching. We had the opportunity to have full access to notebooks and sketches and to frequently meet experienced architects. For the purpose of our analysis, the selected sequences had to present original ideas, to be relatively new and of different types. We selected two sequences of thinking sketches (made by an architect alone) and one sequence of talking sketches (made by the same architect and other architects talking). The first sequence presents a research for an innovative sun-breaker solution. The second sequence presents an exploration to imagine original shelves for the agency. At last, the third sequence consists in a work to imagine a new façade for a police station. These sequences correspond to the earlier stages of the design process and end with the emergence of an original idea. The first sequence consists of one page of notebook (A5 format), the second, of six pages, and the third, of twenty pages of notebook.

3.2 C-K theory to understand design strategies and generative effects behind sketches

In order to better understand the design strategy followed by the designer and the generative effects produced by the sketching activity, the C-K design theory (Hatchuel and Weil, 2003, 2009) was used to model the alternation between concepts and knowledge involved in these sequences of sketches.
Since Concepts and Knowledge are by definition propositions, it was impossible to categorize drawings, which are non-propositional devices, in the C-space or in the K-space. In order to analyze the sequences of sketches, the architect was asked to comment the different sketches by explaining what his reasoning was while drawing. Each sketch could then be associated with statements made by the architect and these statements were qualified as either Concepts or Knowledge. The sketches were put into another space, called D-space. Even if the selected sequences of drawings were relatively new, the fact that the C-K analysis was led after the production of sketches may have involved small deviations from the actual design reasoning: first, the architect may have forgotten some elements about what his design reasoning really was when sketching. Second, the K or C statuses, and thus, the design reasoning modeling, are strongly related to the designer's reference frame and interpretation.
In addition to the four classical operators C->C, C->K, K->C and K->K, the implication of a non-propositional device in the design process potentially introduces four new operators:

- K->D: this operator corresponds to a situation where the designer puts a knowledge that he has already in mind, into a sketch. That could be to visualize this knowledge or even to test it.
- C->D: This operator allows transferring a concept imagined by the designer into a sketch; since concepts have a non-logical status, this operator could help clarifying concepts by visualization.

- D->K: This operator corresponds to a situation where the sketch brings new knowledge to the designer, knowledge he did not have previously in mind thinking about the initial subject. This knowledge can be less or more related to the original concept C0.
- D->C: With this operator, the sketch directly gives birth to a concept i.e. a proposition with a non-logical status (For example, the architect sees a "building as a puzzle" in its drawing).

Moreover, in order to identify the nature of the new insights brought by sketches to the designer, we chose to distinguish K-elements related to the exploration (architectural elements related to the initial topic, aesthetic expectations or evaluation criteria as stability or cost) and knowledge that appears unrelated to the initial topic. For example, the knowledge "puzzle" in our example does not appear directly related to an exploration around buildings. We thus note K* knowledge that appears unrelated to the initial topic. However, concepts could not be distinguished in the same way because alternative concepts are formulated in relation to the initial concept they refine. An example of sketches' analysis is presented below (Figure 1 and Table 1).

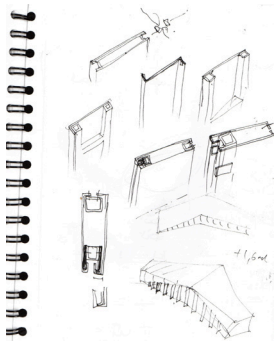

Figure 1. Sequence 1 on an innovative sun-breaker solution

Table 1. Sequence 1: Related statements, K or C status, and related operators

Sketch	Related statements	K or C status	Related operator
	"This is the initial project."	K: initial project of the architect	K->D
	"It is to costly."	K: evaluation	D->K
	"How to realize a cheaper system?"	C: a cheaper innovative system	K->C
	"This system works."	K: experience	K->D and D->K
	"It would not suit for aesthetic reasons."	K: client's taste	D->K
	"How to find an in-between solution?"	C: an in-between system	D->C
	"The H structure is stable."	K: architect's experience	K->D
	"The plate-structure junction can be done from the inside, like this."	K: architect's experience	K->D
	"The final appearance would be this one."	K: final appearance	K->D
	"Something happens at the side."	K*: focus on the sides	D->K*
	"How to fix the plates to the structure by the sides?"	C: a junction system to fix plates and structure by the sides	K*->C
	"Fixation by screwing is not aesthetically pleasing."	K: screwing, aesthetic expectations	K->K
	"The plate-structure junction can be done with a clipping system."	K*: a clipping system	C->D and D->K* (conjunction)
The two remaining drawings were added after this thinking process			

Whereas the four classical operators describe what happens in the designer's mind alone, the four additional operators describe the interaction between the designer's mind and his sketch. For each sequence of drawings, the succession of operators was established in order to draw the design strategy (Table 1). The number of K->D, C->D, D->K and D->C operators was also summarized to help visualize their occurrence and explain the impact of sketches (D-space) on the design process.

4 RESULTS: NEW KNOWLEDGE AND K-REORDERING TO SUPPORT THE DESIGN STRATEGY

4.1 Succession and occurrence of the different operators

The Table 2 below presents the succession of operators for the three sequences. In the "operators' succession" section, the double slash // corresponds to a change of sketch. It also summarizes the occurrence of each operator in relation to the D-space (K->D, C->D, D->K, D->C) in each sequence.

Table 2. Succession and occurrence of operators

Sequence	Operators' succession	Operators occurrence	
1	K->D; D->K; K->C // K->D and D->K; D->K; D->C // K->D // K->D // K->D; D->K*; K*->C // K->K; C->D and D->K*	K->D	5
		C->D	1
		D->K	5 (2 D->K*)
		D->C	1
2	K->D; K->D; K->C // K->K; K->D; D->K; D->K*; K*->C // K*->D; D->K*; K*->K; K*->C //K->D // K*->D // K->D // K->D // K->D; D->K*// K->D; D->K // K->D; D->K*; K*->C // K*->D //K->D // K->D // K->D // K->D; D->K; K->C // K*->D; D->K; K->C // K->D; D->K*; K*->C // K*->D; D->K; D->K; K->C// K*->D; D->K* and K*->D; D->K	K->D	21
		C->D	0
		D->K	13 (6 D->K*)
		D->C	0
3	K->C; K->C; K->D; D->K; K->C and D->C; D->K // K->D and D->K; D->K; D->K // K->D and D->K; K->D and D->K; K->C; K->D; K->C // D->K, then K-D and K->C; D->K // C->K* and K*->D // K->D; K->D and D->C; D->C; K*->D and K*->C; K->K; K->K; K->C and C->D; D->K*; K->D; D->C; D->K*; D->K; K->C // C->D // C->D and D->K; D->K*; K->C // K->D; K->D // K->D // K->D; K->C // K->D; C->D // C->D and D->K; // K->D // K->D // K->D; K->K; D->K*; K*->C // C->D; K*->C and C->D // C->D; D->K* and K*->D // K->D; D->K; D->K; D->K and K->K	K->D	22
		C->D	8
		D->K	19 (5 D->K*)
		D->C	4

4.2 Results analysis

4.2.1 Sketches refer to both Concept and Knowledge

The earlier stages of the architectural design are often associated with fuzzy drawings and fuzzy ideas. Therefore, it can be expected that early sketches refer mostly to Concepts rather than Knowledge. Very surprisingly, each sketch of the three sequences refers most of the time to both Concepts and Knowledge statements.

4.2.2 How sketches bring new insights to the architect

The architect puts a lot in his sketches. In some drawings, he tests a knowledge: this corresponds to a K->D operation. For example, in the sun-breaker solution sequence, the architect tests the H structure to see if it will suit him. Other drawings show an attempt to visualize and refine a concept that the architect has in mind: this corresponds to a C->D operator). For example, the architect tests the concept of "an original clipping system to fix plates and structure by the sides" through a sketch, and since it works, a conjunction appears.

However, the architect also receives a lot of knowledge and concepts from his sketches with the D->K and D->C operations. These K- and C-elements can be knowledge and concepts that the designer had previously in mind thinking about the initial concept: for example, several D->K operations correspond to an evaluation made by the designer looking at his sketch. Here, the K element refers to knowledge belonging the initial K0 basis (regulation, aesthetic requirements, personal expectations).

Nevertheless, several D->K operations correspond to new knowledge. Indeed, the architect sometimes reads knowledge that he did not have previously in mind thinking about the initial topic i.e. knowledge outside the K0 basis: this new knowledge can be a K-element related to the initial topic, but also a K*-element that appears unrelated to the initial topic. This D->K operation can give birth to a concept following a D->K->C succession (D->K, then K->C). Sometimes, a new concept can also be read directly from the sketches without previous knowledge reading: for example, looking at the first and the second sketches of the sun-breaker solution sequence, the architect wonders if it would be possible to imagine an "in-between" system (new C). These results confirm that sketching allows the designer to read new insights in his sketches.

However, sketches bring far more frequently new knowledge than new concepts: the very high number of K->D and D->K operators in comparison with the number of C->D and D->C operators (Table 2) shows that the architect plays mostly with knowledge rather than concepts. He therefore follows a K-oriented design strategy.

4.2.3 An important work of K-reordering

Then, the architect can test pieces of K through his sketches. Sketches also bring new knowledge to the designer and the latter can directly test this new K by further sketching. Therefore, the architect constitutes a reduced K-basis, where each K is carefully selected, tested, and if necessary, removed. This corresponds to an important work of knowledge structuration and reorganization. For example, in the second sequence, the architect wishes to find new shelves design for the agency: the shelves should allow introducing glass tiles and also reflect the agency's identity. The Figure 2 presents some extracts of the sequence in the order of achievement. On several occasions, the architect reads an original knowledge in his sketches and chooses to test it: For example, in the first sketch, the designer sees a Chinese motif that appears to be stable thanks to intertwining lines. The designer chooses to work with this motif throughout the sequence - as we can see in the second and the sixth drawings-, and then keeps this new K in his K-basis. In the third sketch, he is testing alternatives of the intertwining motif. Observing the sketch, he sees a linear form that made him consider using cables. Here again, he chooses to test this new knowledge as we can see in the fourth and fifth drawings. However, gazing at the fifth sketch, he realizes that cables do not allow glass integration: he thus gives up the idea of cables and withdraws this K-element from his K-basis. We can therefore see that, if the selected K does not suit the architect's requirements, it is removed from his K-basis.

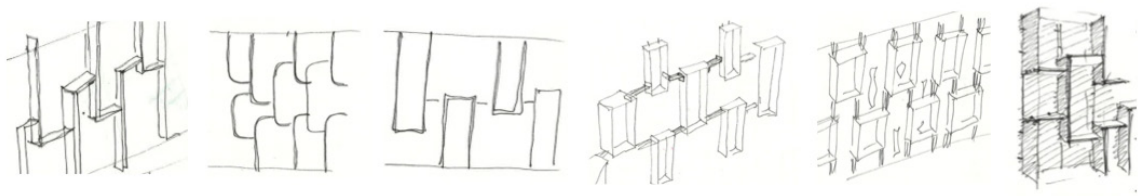

Figure 2. Extracts from Sequence 2 on innovative shelves, presented in order of realization

4.2.4 Nature of new Knowledge

These new K brought by sketches can be related to the initial topic, but can also appear unrelated to the original topic (K*-elements). In the shelves sequence, this is the case for the Chinese motif and the

cables: these two K*-elements have no connection with the shelves topic. Similarly, knowledge on biological cells is introduced in Sequence 3 to design a new façade. Moreover, in each sequence, the number of D->K* operations is quite high looking at the total number of D->K operators: very surprisingly, a lot of new knowledge brought by sketches do not appear to be related to the initial concept C0. Then, sketches have the ability to help the designer to mobilize knowledge that he would not have spontaneously related to the initial topic. In other words, sketches allow mobilizing knowledge not directly related to the C0 nor even to the ongoing exploration. We can easily understand that these unexpected pieces of knowledge K* allow introducing originality in the concepts proposed. However, since the designer follows a K-oriented strategy, it is interesting to look at the effects of the K* on the K-basis itself. The cables are an example of K* that the designer chooses to definitively draw aside of the exploration, as soon as he realizes that this K*-element does not allow fulfilling one of his requirements. In fact, the K*-element "cables" involves determinism in the K-basis since it forbids the use of another piece of knowledge ("glass tiles"). On the contrary, the architect keeps the intertwining motif in his K-basis. It can be noted that this K*-element allows creating interdependence (no modularity) in the K-basis without involving determinism: with an intertwining motif, the stability, glass integration and identity requirements become strongly linked to one another. A stable intertwining motif can allow glass integration and respect for the firm identity (no determinism) but not every stable intertwining motif allows glass integration or respect for the firm identity (no modularity).
Therefore, this K-reordering suppresses modularity and determinism in the Knowledge basis, which fosters the production of a completely new object (Le Masson, Hatchuel and Weil, 2013). This contributes to explain the generative power of the K*-elements, and thus, the generative power of sketches bringing unrelated knowledge to the designer.

5 CONCLUSION

5.1 Understanding the generative effects of sketches with C-K theory

This study allows to better understand the generative effects of sketching by clarifying:

- The nature of the new insights brought by sketches: sketches refer most of the time to both knowledge and concepts. However, new insights brought by sketches, even if they may be concepts, are mostly knowledge. This knowledge is either related or unrelated to the initial topic;
- The strategy followed by the designer and how sketching supports this strategy: here, the designer follows a K-oriented strategy and not a C-oriented strategy as might be expected. Sketching supports this strategy by providing new knowledge less or more related to the initial topic;
- The generative effects of knowledge brought by sketches: the designer carefully tests related and unrelated knowledge and often keeps in his K-basis knowledge that allows suppressing modularity and determinism. The production of an original object is therefore enhanced.

5.2 Implications for design practice

Design theory brings new dimensions in understanding the nature of sketching: the non-obvious combination of C- and K-elements in sketches explains that they might have been considered exclusively as either fuzzy concepts or basic knowledge. It also provides new insights to analyze the way non-propositional devices – such as models, prototypes, drawings or images – impact the design process: in addition to the C- and K-spaces and the four classical operators, the implication of a non-propositional device introduces a new space D and four new operators. Whereas architects tend to be depicted as working mainly with concepts, there is in fact an historical tradition of knowledge combination in architecture: designers actually operate an important work of knowledge structuration.
Moreover, the efficiency of this structuration appears closely linked to the nature of the new knowledge introduced. It would be interesting to study more precisely the conditions under which the introduction of new knowledge helps producing a new object. In our study, new knowledge involving originality consists in knowledge breaking existing rigidities i.e. classical rules within the initial knowledge basis, such as modularity or determinism. Thus, even if it seems unrelated to the initial topic, the introduction of this original knowledge is no mere coincidence: it follows from the very knowledge structure related to the topic from the very beginning of the exploration.

This study therefore highlights the importance of the knowledge structure in idea generation. One could thus imagine to evaluate and manage creativity sessions with different rules: 1/ to look at the knowledge structure generated, instead of the number of ideas 2/ to target knowledge leading to K-reordering, i.e., to generate little original knowledge in order to recompose the initial knowledge basis and favor the production an original object. Finally, thanks to their ability to combine several knowledge and concepts, non-propositional devices could prove to be a privileged means of promoting K-reordering during creativity sessions.

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