C-K Design Theory

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The C-K Design Theory

The C-K Design Theory (C for Concept, K for Knowledge) was introduced by A. HATCHUEL and B. WEIL in 1996 [HaWe-2003] [HaWe-2009] and is today the subject of numerous articles in scientific literature. Recent research covers its implications, practical applications, and its new developments. In this chapter the most recent formulations and the fundamental principles of the C-K design theory are provided without necessarily giving the details of the formalisms applied in this theory.

1.1.4.1. Origins and intuitive motivation

The expectations to the C-K design theory are fivefold:

- From the point of view of contemporary innovation challenges: A theory that is able to address design issues that can't be addressed with traditional problem solving and optimization methods, such as "the design of new usages for emerging technologies", "the design of products/services on very open briefs" (e.g. 'smart mobility'), "the design under very strong constraints" (e.g. 'zero energy', 'frugal innovation', etc.).
- From the point of view of designing professions: Providing a "unified design theory", similarly useful for all kind of designing professions (e.g. industrial design, engineering design, architectural design,…)
- From the point of view of formalisms: A formal model that accounts for "radical creativity", i.e. with strong generativity[1]
- From the point of view of methods: A theory that creates and supports methods for the process of so-called 'inventing' or 'discovering' (and actually designing) new functional requirements and the extension of design parameters.
- From the cognitive point of view: A theory and related methods for overcoming fixations[2]

To give an intuitive motivation of the C-K design theory, one can keep in mind that the theory focuses on the issue of characterizing a design task, its initial point, usually called "brief" or "program" or "specifications": Contrary to "mapping based" design theories (such as programming, problem solving, optimizing, all derived from Simonian theory of design[3]), that tend to clarify the initial task to design *inside* a given mapping, the C-K design theory seeks to preserve the ambiguity, equivocality, incompleteness or fuzziness of the initial brief, precisely because these features will enable to regenerate the mapping itself. The C-K design theory hence models the design of a *desirable but partially unknown 'object'*, which is undecidable whilst applying initially available knowledge. This intuitive motivation raises critical formal issues: How to rigorously reason on a partially unknown object? How to account for the evolutions of the knowledge that needs to be generated and / or has to be extended through the design process? These issues are addressed in the C-K design theory, as it will be shown below.

1.1.4.2. Main definitions and properties

The underlying principle of the C-K design theory is to model design as an interaction between two spaces, the space of concepts (C) and the space of knowledge (K), with the following definitions and implications (see also **table 1.x**):

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1 Generativity is the capacity of a design theory to produce 'novel' solutions from a given knowledge background (see academic references in Le Masson et al. 2017).

2 Fixation (in design and creativity cognition) describes the fact that, in a design task, designers tend to explore only a limited set of alternatives. They are cognitively hindered to explore the whole set of imaginable alternatives (see academic references in Le Masson et al. 2017)

3 The Simonian Theory of Design, formulated by H. A. SIMON in the 1960ies, is based on search algorithms in complex combinatorial problem spaces (c.f. e.g [Simo-1997]).

- **Definition of K space:** The K space is composed of propositions characterized by the fact that they *all have a logical status* (true or false).
- **Definition of C space:** The propositions of the C space are characterized by the fact that they *are interpretable but undecidable with respect to the actual existing propositions in the K space.* Consequently, given the actually available knowledge, it is not possible to prove whether they are true or false. To solve this issue, the expansion of knowledge is needed (see Section 1.1.4.3). Note that this is relative to K (K-relative). With another reference to K, a proposition might become true (or false).
- **Structure of C:** Concepts are of the form "C_n = *there exists a (non-empty) class of objects X for which a group of properties $p_1, p_2, \ldots p_n$ is true in K*".
- **Structure of K**: The structure of K is a free parameter of the theory. This corresponds to the fact that design can use any type of knowledge, but also all types of logic, true or false; K can be modelled using simple graph structures, rigid taxonomies, flexible object structures or specific topologies or Hilbert spaces if there are stochastic propositions in K. The only constraint, from the point of view of C-K design theory, is that propositions with a logical status (decidable) might be distinguishable from those that are not decidable.

1.1.4.3. Design process: C-K partitions and operators

A design starts with a concept C_0, a proposition that is undecidable with the initial K space. The theory formalizes how this undecidable proposition becomes a decidable proposition. This is realised by two processes, *expansions* in K and *partitions* in C:

Expansions in K: It is possible to expand the K space (by learning, experimentation, remodelling, etc.). This expansion can continue until a decidable definition for the initial concept is obtained in K* (expanded K).

Partitions in C: It is possible to add attributes[4] (known in K space) to the concept to promote its decidability. This operation is known as *partition*. In the C-K design theory, the partitions of a concept C_0 are the classes obtained by adding properties (from K space) to the concept C_0. Formally, adding p_{n+1} (taken from K) to C_n gets: C_{n+1} = *there exists a (non-empty) class of objects X for which a group of properties $p_1, p_2, \ldots p_n, p_{n+1}$ is true in K.*

Implication 1: These expansions continue until they come up against a proposition derived from C_0 that becomes *decidable* in K* (i.e. expanded K, as it is when the decidability of the concept is studied, i.e. when the proof of existence is obtained). The concept then becomes a true proposition in K*. In C-K design theory, this is called a *conjunction*.

Implication 2: A partition presents a rather specific problem: What is the status of the new C_{n+1} ? This status must be "tested", i.e. its decidability with respect to the K space must be studied. This corresponds to making prototypes, mock-ups and experimentation plans. In turn, these operations can lead to expansions of the K space that are not necessarily related to the concept being tested (surprise, discovery, serendipity, etc.). The test has two possible results for C_{n+1}: Either C_{n+1} turns out to be undecidable with respect to K and the proposition therefore becomes a K space proposition, and the design ends in success; or C_{n+1} remains undecidable in terms of K and the proposition is in C space.

All the operations described in the C-K design theory are obtained via four elementary operators representing the internal changes within the spaces (K→K and C→C) and the action of one space on another (K→C and C→K):

4 Not to be confused with the "attribute" term applied in Integrated Design Engineering (see Chapter 2 for its definition and description)

1. The classical operations of inference, deduction, decision, optimization, etc. are operations of K in K.
2. The operator K to C, the disjunction operator, consists of creating a new undecidable proposition in C on the basis of decidable propositions in K.
3. The operator C to K, the conjunction operator, consists of creating decidable propositions in K on the basis of undecidable propositions in C.
4. The operator C in C generates undecidable propositions on the basis of other undecidable propositions, using only C propositions.

Table 1.X provides both a synopsis and a glossary of main definitions and first results of the C-K design theory.

Table 1.X Glossary of main definitions and first results of the C-K design theory

1	A set of propositions having a logical status is known as **K space**
2	The addition of a proposition in K is known as an **expansion of K space**. By definition this proposition has a logical status
3	Given a K space, a proposition of the form {x, P(x)}, interpretable in the base K (P is in K) and undecidable in base K (P is in K), is known as a **concept** (the proposition {x, P(x)} is neither true nor false in K).
4	The addition of some supplementary property to the concept (which becomes {x, P(x), p_k(x)}) is known as a **partition**. • Remark: C is K-relative. • In a set-wise approach, a concept is a set from which no element can be extracted • Theorem: A concept space has a tree-structure.
5	Given a concept and its associated base K, an **operator** is an operation (using K or C) consisting of transforming a concept (partition) or of transforming the K space (expansion). Primary operators: C→C, C→K, K→C, K→K.
6	K→C is the **disjunction** operator: Passing from decidable propositions to an undecidable proposition (using the known to work in the unknown)
7	C→K is the **conjunction** operator: Passing from an undecidable proposition to a decidable proposition (using the unknown to expand the known)
8	Given a space K and C ({x, $P_1P_2…P_n$(x)} on this space K, an **expansive partition** (conversely **restrictive**) is a partition of C making use of property P_{n+1} which, in K, is not considered to be a known property associated with X (nor with any of the P_i, i<=n) (conversely a property P_{n+1} such that P_{n+1} is associated with X in K or there exists an i, i<=n such that P_i and P_{n+1} are associated in K).

1.1.4.4. Main implications

One of the immediate results from the C-K design theory is that, for a given C_0, the C space necessarily has a **tree structure,** as the tree structure is a consequence of the order relation created by successive partitions.

Second, the C-K design theory allows the distinction between **two types** of **partitions**: Restrictive partitions and expansive partitions. A concept is interpretable hence it relates to some knowledge in K. A restrictive partition is a partition that uses attributes coming from the knowledge associated to the concept or compatible with it. By contrast, an expansive partition is a partition that makes use of attributes that are not compatible with this knowledge. Expansive partitions

- lead to revision of the definition of objects,
- steer the exploration towards new knowledge that is no longer deduced from the available knowledge.

The generative power of the C-K design theory relies on the combination of these two effects of expansive partitions.

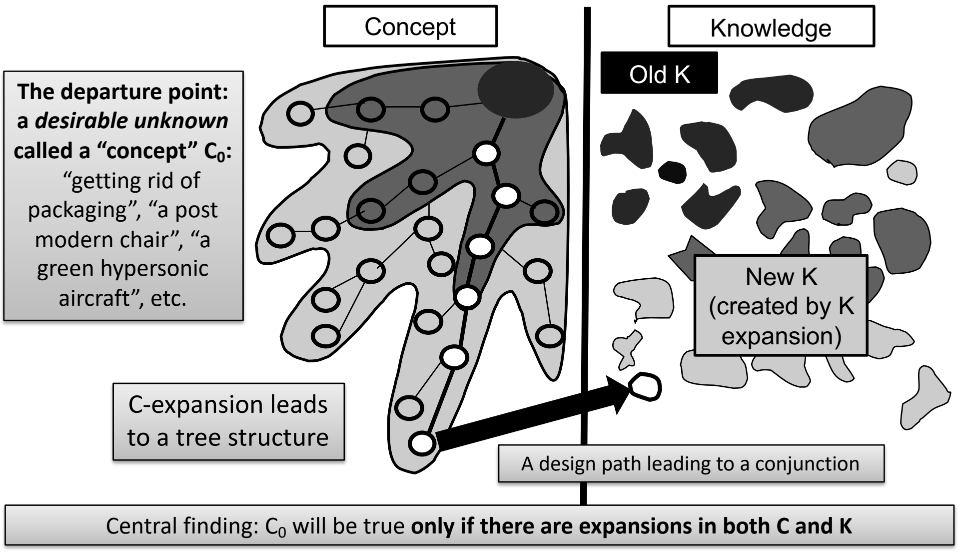

Figure 1: Diagram summarizing the C-K design theory [MaWH-2017, p. 140]

In the following there is a very simple example to illustrate the different C-K notions. For real case examples see for instance [MaWH-2017].

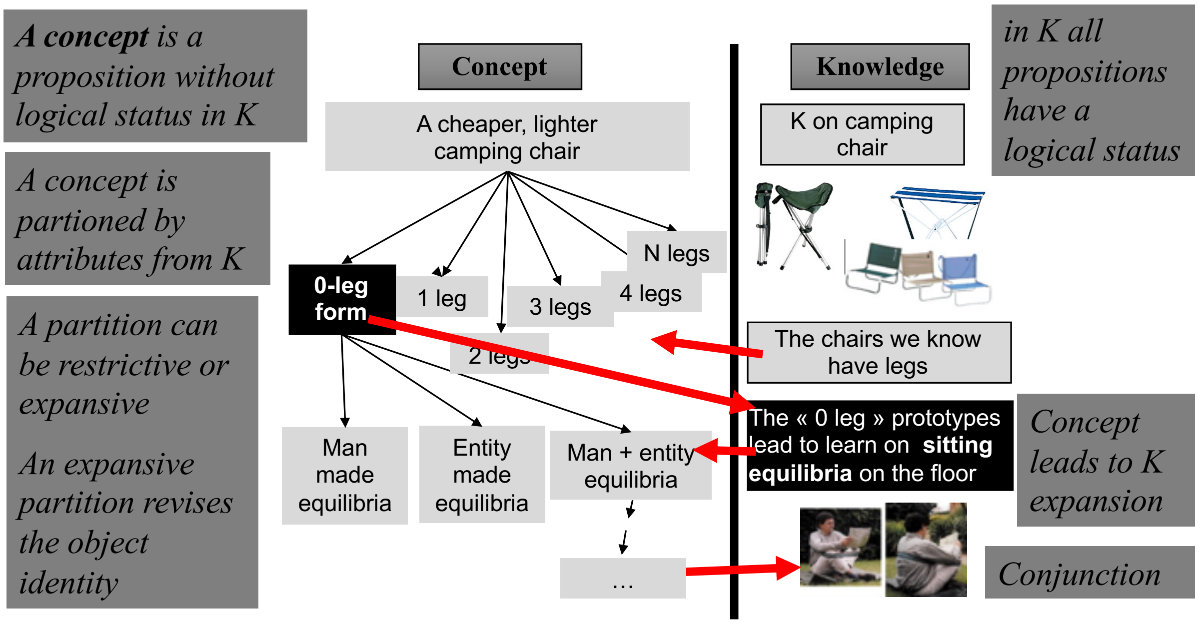

Figure 2: A very simple case to illustrate the main notions of the C-K design theory [MaWH-2017, p. 137]

1.1.4.5. Some implications

While the presentation of the C-K design theory here is still succinct, the reader can be assured that, using the elements given above, the theory meets the initial expectations expressed in section 1.1.4.1:

- The theory is well adapted to address the types of innovation listed in section 1.1.4.1.
- "Professional expectations": The theory enables the relationship between the K-oriented professions (engineering) and the C-oriented professions (design) to be considered. It also reveals that there is K in design and C in engineering.
- Formal expectations: Taking note of the creative act: See the notion of expansive partition, heredity, conceived ontology, invariant ontology, etc.

- Methodological expectations: The theory allows the revision of object definitions, and hence the extension of the list of functional requirements and the design parameters.
- Cognitive expectations: The C-K design theory enables the effects of fixation to be overcome: A fixation will arise from the definition of certain objects; indeed, the theory allows these definitions to figure in K space, then to be rigorously and systematically rediscussed via expansive partitions in C.

Several techniques, methods, and processes have been developed based on the C-K design theory to support innovative design processes and organizations.

Intense research work has led to deepen and reveal the theoretical foundations of the C-K design theory (C-K design theory and forcing, generative knowledge structures, C-K design theory and logic,…).

1.1.4.6. References and further readings

[HaWe-2003] Hatchuel, A., Weil, B.: A new approach to innovative design. An introduction to C-K theory. In: Norell, M. (Editor): ICED03, Research for Practice – Innovation in Products, Processes and Organisations. p 14

[HaWe-2009] Hatchuel, A., Weil, B: C-K design theory: An advanced formulation. Research in Engineering Design 19(2009)4, pp181-192.

[MaWH-2017] Le Masson, P., Weil, B., Hatchuel, A. (2017) Design Theory - Methods and Organization for Innovation. Springer International Publishing AG. doi:10.1007 / ISBN 978-3-319-50277-9

[Simo-1997] Simon, H. A.: The Sciences of the Artificial. MIT Press, Cambridge (USA), third edition 1997

An introduction to the C-K design theory can be found in:

Agogué, M., Hooge, S., Arnoux, F., Brown, I.: An Introduction to Innovative Design - Elements and Applications of C-K theory. Sciences de la Conception. Les Presses de l'Ecole des Mines Paris 2014

A comprehensive synthesis of the theory and several examples can be found in:

Le Masson, P., Weil, B., Hatchuel, A. (2017) Design Theory - Methods and Organization for Innovation. Springer International Publishing AG. doi:10.1007 / ISBN 978-3-319-50277-9

Glossary

K space *(K = knowledge) :* In C-K theory, the **K-space** is a set of propositions with a logical status. An expansion of K-space is the addition of a new proposition in K.

Concept : in C-K theory, given a K space, a **concept** is a proposition {x, P(x)}, interpretable with K (P is in K) and undecidable in K (the proposition {x, P(x)} is neither true nor false in K).

Partition of a concept *(C-partition) :* in C-K theory, a **partition** is the addition of a supplementary property p_k to the concept (which becomes {x, P(x), p_k(x)}

Operators in C-K *(C-K operators) :* Given a concept and its associated base K, an **operator** is an operation (using K or C) consisting of transforming a concept (partition) or of transforming the K space (expansion).

Primary operators: C→C, C→K, K→C, K→K.

Disjunction : K→C is the **disjunction** operator: Passing from decidable propositions to an undecidable proposition (using the known to work in the unknown)

Conjunction *:* C→K is the **conjunction** operator: Passing from an undecidable proposition to a decidable proposition (using the unknown to expand the known)

E*xpansive partition (resp. restrictive partition) :* Given a space K and C ({x, $P_1P_2\ldots P_n(x)$} on this space K, an **expansive partition** (conversely **restrictive**) is a partition of C making use of property P_{n+1} which, in K, is not considered to be a known property associated with X (nor with any of the P_i, i<=n) (conversely a property P_{n+1} such that P_{n+1} is associated with X in K or there exists an i, i<=n such that P_i and P_{n+1} are associated in K).

CV

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Armand Hatchuel, Pascal Le Masson, and Benoit Weil work on design theory and methods for innovation. They have published “Strategic Management of Innovation and Design” (Cambridge University Press, 2010) and “Design theory” (Springer, 2017) and several papers in international journals.

They conduct collaborative research with several companies in particular with the partners of the DTMI Chair: Airbus, Dassault Systèmes, Renault, SNCF, ST-Microelectronics, Thales, Urgo, Nutriset, Spoon, Cayak, and Stim