Climbing c-trees : analysing concept-tree content and construction

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CLIMBING C-TREES: ANALYSING CONCEPT-TREE CONTENT AND CONSTRUCTION

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The aim of the paper is to analyze the rationale of production of C-trees used in innovative design implementing C/K theory.
Data had been produced within industrial creative workshops in four medium-sized industries. Workshops had been conducted by the researchers and 5 C-tree had been produced and analyzed. Existing patterns and rationale in the construction of the C-trees are researched. The Analysis of the content and structure of the C-trees shows that five types of partition are used. The sequence of partition doesn’t show any pattern. The subjectivity of the representation is illustrated. Mechanisms of systematic expansion of C space are also illustrated through the C-tree analysis. Based on real cases, the paper discuss practical use of C-tree as intermediary object.

1 INTRODUCTION

The research project described in this paper had been conducted with three medium-sized enterprises in France. Companies are similar in term of structure but operate in different markets; these three companies are reputed as innovative companies from outsiders even if R&D managers say “we are not innovating enough”. They had difficulties in managing organisational ambidexterity (Voss 2012) in order to address disruptive innovation because all resources are focused on exploitation. Continuous improvement of product, development of project, client answering and support consume most of resources in the R&D teams. Arbitration in activities is often done on short term criteria. To limit resource waste, lean management started to be implemented in product development after being mostly deployed in manufacturing. But we observed that a systematic and holistic approach of lean development is hard to be implemented. It is often reduced to waste reduction focus or tool implementation. Actually, this deployment tends to reinforce the exploitation tendency while project are more formalized and standardized. On the contrary the fuzzy front-end and upstream exploration processes are less structured and performance indicators harder to choose and estimate. Exploration capacity is then based on individual ambidexterity (Raisch et al. 2009) while upstream phases are poorly structured. The knowhow on innovative design has not been fully appropriated by the three industrial medium-sized companies even if Design thinking had been popularized in industry by authors like Tim brown and companies like IDEO (Brown 2009). The progress of research in design thinking go beyond the brown's definition of design thinking (Kimbell 2012; 2011) (Leifer & Steinert 2011) and the lack of knowledge on design theories and state of the art make the appropriation of existing methods difficult. It is also noticeable that literature often refers to success stories or theoretical aspects more than difficulties and practitioner feed-back.

The aim of our research project was to cope with this difficulties with a joint research program with R&D managers and their teams. During this four year research project we had co-developed the **Créat'Inn** method with companies. This method integrates medium-sized enterprise constraints and is based on state of the art design Thinking Theories. Among the state of the art knowledge imbedded in the **Créat'Inn** method, we used the C/K theory principles (Hatchuel & Weil 2008; Hatchuel et al. 2004). C-tree models had been produced and had been used during the process. The present paper will focus on the analysis of construction and structure of the C-Tree models. As define in (Hatchuel et al. 2004) "a concept C is a proposition which has no logical status in a space K (i. e. nor false nor true in K)". the Space concept has a tree structure "as the only operations allowed are partitions and inclusions and it has initial disjunctions". Thus we call C tree the representations build to organise the C space during the Créat'Inn process. The abstract level of C-tree had been well described in the foundation of C-K theory (Hatchuel & Weil 2008). It has been also presented to illustrate the design process performed or past exploration for example in (Garel & Mock 2012). But few had been told to help practitioners to deal with their constructions during innovative workshops. Can the C-tree be useful intermediary object of design (Boujut & Blanco 2003; Jeantet 1998; Vinck & Jeantet 1995) and if so what are the rules of construction. During production phase the session animators had encounter difficulties to fix C-tree representations and later as they appears to be essentially subjective. Analysis of C-tree shows they have different characteristics even if the same team had produced them in different contexts.

The paper will present shortly the **Créat'Inn** method in the following section to show the step when C tree were produced. Then methodology of research will be presented. Follows the analysis of the Five C-trees produced during workshops. Then we'll analyse the C-tree construction process and discuss characteristics of the C-tree analysed.

2 CRÉAT'INN

The process is composed of three phases, four workshops and two milestones. The full process lasts four to six months without iterations. The timeline of the process is represented on figure 1.

2.1 Workshop 1: Re-formulate the initial concept

The workshop 1 lasts half a day and mobilizes eight to sixteen participants, including two animators. It consists in establishing the state of the art, based on the nine screens representation: the system, subsystem and super-system in their present, past and future state. After the workshop 1, the animators sum-up the exchanged informations in a C-Tree representation.

2.2 Workshop 2 : Identify essential Ki and formulate C0

The workshop 2 lasts half a day and mobilizes the participants of the workshop 1. The initial C-tree is presented and used to redefine the perimeter of the project and the innovation field to be explored. The formulation of C0 initial concept is fixed. Essential fields of knowledge (Ki) are identified and selected for further exploration.

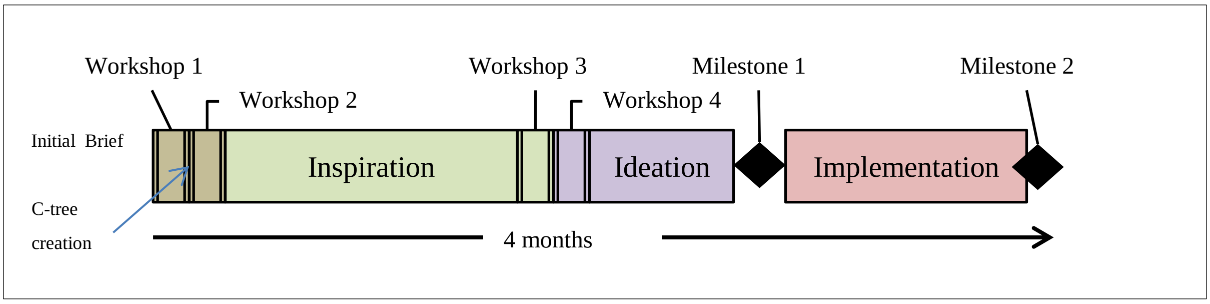

Figure 1: Time line of the innovative process

2.3 Inspiration phase:

2.3.1 Collect essential Ki

During the Inspiration phase, a core team – four to eight participants of the previous workshops – explores the fields of knowledge (Ki) selected during the workshop 2. The team meets weekly during half-an-hour sessions within the dedicated room. This phase contains one week of effective work spread over one to two months. This time span allows the team to collect internal or external knowledge considered as essential for the project.

2.3.2 Workshop 3: Share essential Ki

The workshop 3 lasts a full day and mobilizes ten to twenty participants, including two animators. The day is dedicated to essential knowledge exchange by alternating presentations with open discussion and summarizing in group work.

2.4 Ideation phase

2.4.1 Workshop 4: Ideation

The workshop 4 mobilizes the participants of the workshop 3. After a warmup exercise, it is organised in three phases: Idea generation, Idea clustering and selection, sub-group concepts prototyping. Rough prototyping is used to continue creative exploration of ideas or cluster of ideas. At the end of the workshop, each sub-group presents its prototype and the elaborated concept to all the team and the Sponsor.

2.4.2 Ideation continued

After the fourth workshop, the core team of the Inspiration phase meets to evaluate the elaborated concepts obtained during the workshop 4. Concepts that were not picked up for elaboration during the workshop 4 can be given a second chance at this point. The first step of the future development is identified, for example consultation or prototyping. Ideally this step last one week and prepare a formal decision of milestone1.

2.4.3 Milestone 1

At the milestone 1, the concepts selected by the core team have to be approved by an innovation committee or a sponsor. Depending of the organization of the enterprise and the centralization of the decision making, the members of the committee may vary. The concepts allowed to continue further their development are assigned to project manager, preferably among the members of the core team.

2.5 Implementation phase

2.5.1 Preliminary studies

During the Implementation phase, feasibility study is carried out. Pre-dimensioning, modelling analysis, initial drawing, tests and functional prototypes are realised. This phase allow to consolidate knowledge around concepts and to formalise the project charter for potential developments, resources needed and schedules.

2.5.2 Milestone 2

At the milestone 2, each project is submitted to a go no-go decision. The criteria used may vary from an enterprise to another since the aim is to switch to a development process already existing in the enterprise. This milestone closes the Créat'Inn cycle.

3 RESEARCH METHODOLOGY

This research had been built as a multiple case study with three medium-sized companies that expect concrete added value from the project in a short term. It means we should assume to intervene in the transformations of the design practices of the companies while researching on it. The research program had been co-constructed with practitioners following a constructivist approach as proposed by Avenier (Avenier 2010). We adopted a research action (Coughlan & Coghlan 2002) process organized in different cycles. We then assume an iterative process inspired from design thinking where proposition where designed and prototyped then monitored and analysed. The research was thus organized in different Steps

1. Company recruitment and enrolment
2. Audit of design practices of the three companies
3. Experimenting **Créat'Inn** cycle in the three companies
4. Follow up of appropriation of the method.

C-Tree had been used in the Third step of the research so we'll focus on this paper only on this step. Additional data were obtained thanks to application of **Créat'Inn** in an operational form as consultancy in a fourth company that have the similar characteristics of medium-sized company referred as partner 4 (P4) in the Table1. The four companies are Intermediate-sized enterprises in the definition of INSEE[1] that are overpass criteria of SME in the sense of EU (European Commission 2015), They all develop and manufacture products.

Table 1: Intermediate sized characteristics of companies

	Sector	Head count	Revenue	Data
P1	Sports equipment	~ 700	~100M€	2 C-tree
P2	Transport	~ 300	~135 M€	1 C-Tree
P3	Painting devices for Industry	~ 230	~70 M€	1 C-tree
P4	*Electric Equipment*	*~600*	*~100M€*	*1 C-tree*

The experimentations of **Créat'Inn** within the three companies were performed sequentially during the research phase. Junior researcher stayed in the company for 6 month during each experiment to work with the core team and senior researchers animated the workshops. This was not the case for P4 Company and in the second project of P1 company which were organised in the consultancy mode, the researcher only animated the workshops.

C-trees had been result of group work and discussions during the sessions; they were used in the workshops. The analysis has been done on the C-Tree posters 1 to 24 month after C-tree production.

The Analysis proposed in the paper is then based on the 5 C-tree models realised and used after the workshop 1 session for each project.

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[1] An intermediate-sized enterprise (ETI) is a company with between 250 and 4999 employees, and a turnover which does not exceed 1.5 billion euros or a balance sheet total which does not exceed 2 billion euros. (http://www.insee.fr/en/methodes/definitions/entreprise-taille-intermedi.htm)

4 C-TREES DESCRIPTION AND ANALYSIS

Due to confidentiality reasons the full C-tree realised during the creative session within the companies cannot be provided. We'll extract examples to illustrate the paper.
The analysed Projects can be differentiated by their starting points which were decided before the first workshop, and the stake of project with regards to expected impact on the company offer. A Small Technical project was focus on the improvement of technical function of one product. A large strategic project could impact many products or core domains of the product.

Table 2: Characteristics of the 5 C-Trees analysed

	Starting point	Stake of project	# Partition layer max	# Concept items
P1	Technology integration	Large strategic	7	44
P2	Client pain point	Large Strategic	6	35
P3	Client pain point	Medium Technical	13	53
P4	*Cost reduction*	*Large Strategic*	*6*	*34*
P1	*Client pain point*	*Small Technical*	*6*	*33*

Table 2 gives some figures of the C-tree dimensions. Number of partition layers represents the maximum number of layer identified in a C-tree. It can indicate the depth of analysis. Number of concept items represents the number of explicit concept represented within the C-tree produced. For example C-tree A in *Figure* 2 has 3 partition layers and 9 Concepts items. P3 project figures show that this subject had been explored by different projects by the past. Thus multiple attribute and C items were shared at this first workshop. Other C-tree figures are similar despite the different starting point and stake of the project.
The analysis of the 5 C-trees content highlights different formulation of partition which can be classified into five categories as described in the following table 3

Table 3: Type of partitions identified in the 5 C-trees analysed

Type of partitions	Definition	Example
Functional	refer to the existence or not of some functions or the performance of a function	with manual lock / without lock / with automatic locking
Architecture	refer to allocation of functions to component or subsystem, existence or suppression of components	Mobile / immobile component / component in one block.
Physical principles	refer to principles to perform technical functions	Digital detection / mechanical detection / combined mech-dig detection.
Characteristic value	present partition on the value of one characteristic	low temperature / very low temperature / high temperature.
Manufacturing principles	refer to manufacturing processes to realise some functions or components	Sewed / welded / bonded / riveted

It is noticeable that the C-trees don't show any patterns that can represent a systematic process of design moving from functional to characteristic value or manufacturing principles. Architecture partitions can follow and precede functional ones and/ or manufacturing principles.
(P1) can be classified as technology push innovation with the aim to explore integration new technologies within a specific product. In the C-tree obtained, the first layer of partitions was functional ones. Organisation of the C-tree suggests the exploration of the new technology introduction on all functions of the product. On the project (P4) the starting point was to reduce product cost. We observe that first layers are architectures partitions. Each C-tree sequence is different

so at this stage we can only observe the differences without being able to advance any hypothesis about C-tree structure.

5 PRODUCTION OF THE C-TREE: A SUBJECTIVE CONSTRUCTION

The C-tree had been built as a synthesis of the first workshop where team participants had described the system through the Multi-screen analysis (Souchkov 2014). The sessions output represent a lot of information and notes. The choice was made to reorganise the data in a C-tree model. This work was dedicated to the animators of the sessions and the C-tree was then validated with the Sponsor of the action and serves as starting point of the second workshop. During this construction, it was observed that C-trees had difficulties to fix the sequence of partitions to represent. It was also observed that the C-tree go beyond the report of the exchanges by introducing new partitions, opening new exploration branches on the tree.

5.1.1 Which partition first?

The sequence of partitions in multiple layers leads to different C-trees that can be candidates for support of discussion. Thus the difficulty encountered by C-trees producers was to decide the order of partitions that should be represented. *Figure* 2 exemplifies two possible partitions A and B for concept CX. This decision has to be taken by the C-Tree producers and as far as we know there are no rules to choose the representation A or B in the Design Theory. Thus C-tree appears to be interpretations and arbitrary choices from C-tree producers.

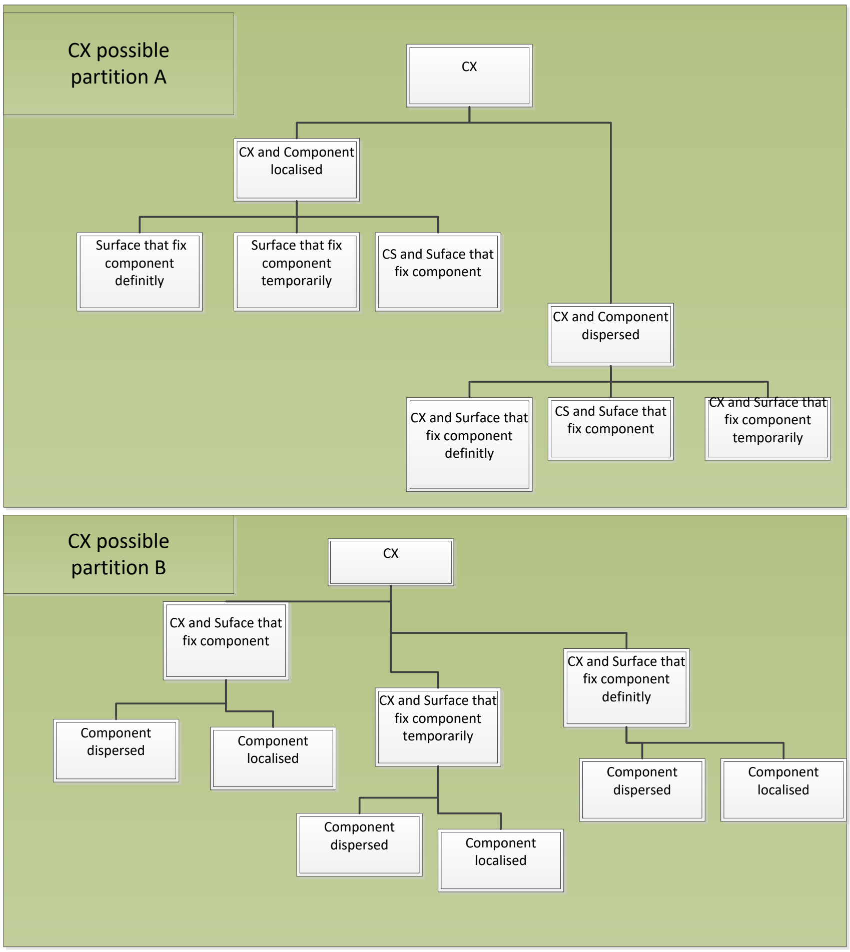

Figure 2: Two possible sequences of partitions

One Choice could be to follow the historical appearance of the partitions or characteristics during the workshop. The rationale would have been to keep trace of the design reasoning process. But we can observe that it was never the rationale followed on the 5 C-trees analysed. C-trees were not built synchronously during the team exchanges; they were built by animators of workshop as a synthesis of

discussions. Another choice could have been to capture historical organisation of precedent explorations presented during the workshop. Analysis of data showed it was not the case. It did not sound relevant for C-tree producers. The collaborative construction of the C-tree leads to discussions and multiple versions of C-tree structure unfortunately not captured as data. The choices of partitions order neither refer to the type of partitions the 5C-trees made by same teams have different structures.
The first workshop objective was to confirm or reformulate if needed, the initial concept for the project. The analysis of sur-system and sub-system allows to question at which level of the system the innovation should be researched. In company (P3) for example, the focus was first on the redesign of a component that insure a specific functionality. This first workshop showed that the customer value has to be researched on the sur-system of this component, at the painting station level. Thus the notion of the roots of the C-Tree becomes a question. Formulation of C0 appears to be critical. During the collaborative process of production the initial concept was reformulated and finally the initial tree became a lower branch of the tree (Figure 3).

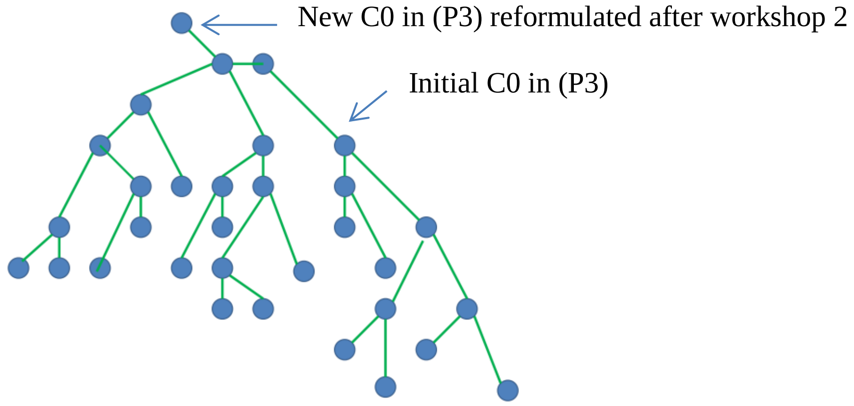

Figure 3: Re-formulation of the C0 in the C-tree

The representation of the C-tree facilitates the emergence of this new formulation of initial C0. But still the mechanism and systematic scheme of construction of the C-tree remain unknown. The construction appears to be "magic" for the practitioners as far as the rationale was implicit and construction rules not explained. Decision of the sequence of partitions appears to be intuitive. Nevertheless the construction of C-tree went beyond the synthesis of workshop exchanges. It allows to re-interpret the workshop 1 content and also to initiate expansion creating new partitions.

5.1.2 Opening systematic partitions

During the construction of the C-tree different partitions appears from the verbatim extracted during the work session. Experts and participants had shared knowledge, experience, previous development and data from market competitors. From these discussions which refer both to K space and to C-Space, key attributes are highlighted as relevant for the purpose of the exploration.
Construction starts with formulating the Concepts items identified in the workshop and organizing them in an initial tree. From there, partitions can appear within the C-Tree using systematic logic value of attribute. For example from a verbatim "Action 1 perform Manually" which can be the state of the art, or a concept previously explored, a partition can be proposed for expansion of C like "Action 1 perform automatically" or "Action 1 not performed". Systematic expansion can open multiple branches on the C-Tree. These elements are not actually present in the discussion but are added in the C-Tree during its construction. This is a useful element of the C-Tree to systematise expansion. For example if an attribute like "locking a component" appears and existing locking is mechanical, other locking technology can be created as concept to expand C-Tree for example: "Chemical Locking", "magnetic locking" "combined mechanical/chemical locking.
Partitions are also obtained moving up in the tree. For example 3 technical solutions can be recognised as related to the same physical principles thus a new physical principle partition can be represented in the tree. Same phenomenon can appear with functions or Architecture partitions
Other principles of expansion were used at this stage on which we can recognise Triz inventive principles (segmentation local quality, asymmetry, dynamics merging, etc…)

Partitions can be also obtained from the identification of disjunction from K discussed during the workshop. For example knowledge from support service express as "rate of 70% of default coming from component X" call for a concept: "a Product without component X".

Thus it cannot be said that C-Tree was only a transcription of exchange realised during the session. The C-tree producers started to organise the previous exploration expressed by the company team and also open new partitions that open new concepts. At this stage the partitions can be considered as formulation of Generative Design Questions (Özgür 2002; 2003) that require explorations for new potential solutions. Thus the transcription of workshops minutes and notes to a C-Tree appears to be a translation which both changes representation but also transforms the content itself. (Jeantet 1998).

6 CONCLUSION

This research explores the implementation of state of the art methods to support exploration project within medium-sized enterprises. Among design thinking theories, principles of C/K theory had been implemented. C-tree had been used as intermediary object to support the creative design. The production of C-tree remains many questions and discussion about construction rationale. .

This paper present a first analysis of production, content and structure of C-tree produced during industrial Innovative workshop. The analysis of the 5 C-tree shows that limited types of partitions are used to expand C space description. The analysis of the C-tree don't show explicit pattern in the succession of type of partitions. The construction process of the C-tree illustrates that decision of partition sequence are based on C-tree producer interpretation. Thus the tool appears to be a subjective representation as it is not supported by any formulated rules of constructions. It is noticeable that even if the C-trees had been realised by the same Producers no clear Patterns are identified across the 5 C-trees. No clear Rationale of C-trees construction could be identified. We also illustrate that the use of C-tree allows to support multiple partitions using different mechanism of systematic partitions.

Extension of the number of cases analysed should be required to allow strong conclusion on pattern identification and typology of partition. Thus accepting subjectivity of C-tree behind the mathematical formulation of C-Space structure can be of value for practitioners.

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