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# Templates of Original Innovation: Projecting Original Incremental Innovations from Intrinsic Information

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ABSTRACT

A systematic framework for the enhancement of inventiveness is introduced. According to the proposed approach, the starting point is an existing system rather than external pressures. By a sequence of formal operations (defined as templates) on the initial structure of a system, an innovative structure involving a new system is obtained. The sequence of operations is prescribed by well-defined procedures. The replacement template is illustrated in this work by two field cases and its potential value is tested empirically. Given the abundance of innovations in which the templates are manifested, the replacement template can be considered an exemplar for utilizing intrinsic information about a system in the development of innovations. © 1999 Elsevier Science Inc.

## Introduction

Prevailing paradigms in the management of innovation view the emergence of innovations as driven by external events such as changes in available technology or in external factors (client needs, physical environment, culture, tastes, the state of the economy, etc.). Accordingly, in forecasting and assessing innovations, emphasis is placed on external factors, while the changes in the system are treated as mere consequences [1]. Addressing potential needs and improving system performance typically results in increasing the complexity of the system [2, 3]. Day, Shocker, and Srivastava [4] argued that increased system complexity arises due to the arbitrary nature of product boundaries, with different decision contexts imposing different definitions of boundaries. Increasing the complexity and crossing the border to a "new to the company" type of innovation is also likely to lead to risks in R&D which firms are reluctant to adopt [5].

In contrast to the "externally-driven" view of system emergence, it has been posited that an examination of patterns observable in the internal dynamics of innovation may yield technological changes that are less expected by focusing exclusively on the

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environment. According to this view, new functions (or improvements) that involve reducing the complexity of the system rather than increasing it are likely to emerge. These less predictable innovations are perceived as "inventive solutions" [3, 6, 7] and are associated usually with "creative leaps" (see the detailed review in [8]). These inventions require less adjustment effort by the manufacturer and although they tend to be "new to the world" they are not "new to the company." Griffin [5] showed that inventions of this type, namely, "new to the world but not new to the firm," tend to be more readily adopted by firms. According to a recently introduced quantitative model for classifying such innovations [9], this type of innovation, which does not require radical changes in the system, is termed "incremental innovation." This article introduces a model aimed at facilitating the emergence of original incremental innovations which, by definition, are relatively difficult to predict. It is posited and demonstrated in a study, that original innovations lend themselves to certain "attractors," which help in channeling the search of innovation into efficient predefined routes.

The observation that "reduced complexity" patterns are associated with originality can be found in Altschuler's [10] prominent study on inventive solutions. By a backward analysis of more than 250,000 inventions in engineering, Altschuler was able to define certain patterns of invention that he labeled "standards," consisting of a system dynamics which can be determined by the intrinsic features of the system. These patterns can be described, predicted, and controlled independently of external perturbations. Altschuler's notion of standards was recently extended into creativity templates [11] (hereafter CT) which are defined as universal structures of change. Creativity templates have been shown to generate systematically superior ideas in the context of New Product Ideation [11, 12]. Both by Altschuler's standards and by the CT taxonomy, it has been observed that originality and inventiveness tend to be attributed to simplicity and to the restricted scopes of the solutions to current systems or products.

Two major templates entailing reduction of system complexity have been identified:

1. The replacement template, defined as the replacement of eliminated components by already existing components in the system or the immediate environment.
2. The displacement template, defined as the removal of the eliminated component's function as well as the component itself.

Contrary to Altschuler's approach, and the use of standard to solve well-defined problems, according to the CT approach it is posited that in order to enhance ideation in an ill-defined situation, instead of waiting for a problem to occur, a template can be used to channel ideation and detect problems or needs yet to be identified. This "reversed path of thinking" is consistent with recent findings in cognitive psychology, based on the function follows forms principle [13]. According to these findings, problem solvers are more creative when they explore new functions for a predefined form rather than searching for solutions (new forms) for predefined functions. The combination of CT and the function follows form principle serves to promote the emergence of the "incipient stages of creative thinking" which, as argued by Kenyon [14] are critically important for system managers or researchers.

The structure of this article is as follows: We start by illustrating an original replacement-based innovation. After presenting a detailed description of how a replacement template can be utilized (via a second field application), we present a study in which the contribution of the replacement template to design is assessed. We conclude with a discussion of the rationale underlying this approach.

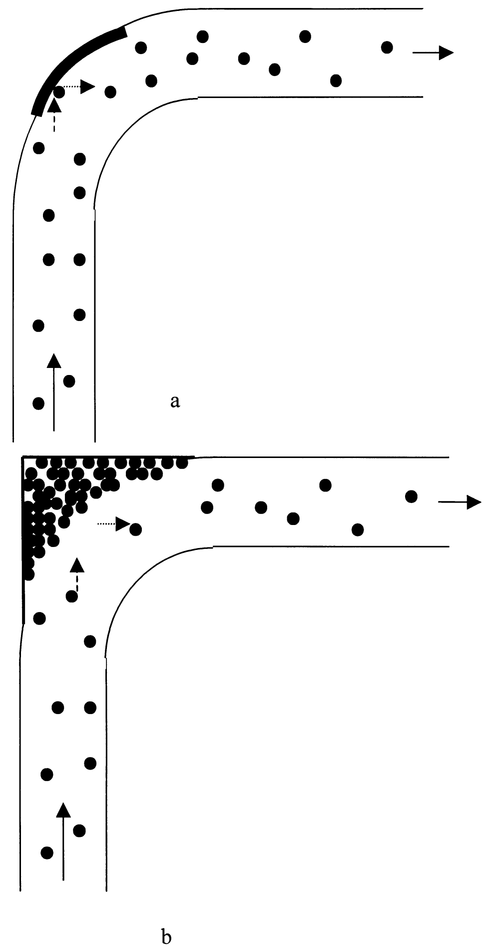


**Fig. 1. a) Curved tube with accelerated spheres. b) Replacement-based innovation in which static spheres are utilized to shield the corner and prevent abrasion by the accelerated spheres.**

## Illustration of "Original Innovation" and a "Replacement-Based Idea"

To illustrate the notion of original innovations, consider the following scenario (Figure 1a): Small spheres are accelerated to high speed in a tube (by airflow). The purpose of the high-speed balls is to provide a surface treatment for metal structures (outside the tube); hence, the spheres are made of a hard and rigid material and their velocity is high. In most systems of this kind, the tube is curved (due to geometrical constraints). As a result, the corner undergoes the same surface treatment and damage is evoked. In a particular system, an additional curved sheet made of strong alloy is placed in the corner in order to isolate it from the fast-moving spheres. The problem is that this shield undergoes the same process of abrasion as the tube's corner and it has to be replaced periodically.

In this particular case, it took more than two decades for the emergence of an (incremental) innovation which solved the problem completely. Until then, most of the suggestions had consisted of altering the flow direction near the corner (very complicated and unreliable) or developing a stronger alloy (the improvement was negligible). These concepts involved high R&D risks and investments. The implementation of the new concept, which solved the problem completely, was extremely simple and straightforward. Instead of protecting the corner by a curved alloy shield, the spheres themselves were used to shield the corner (see Figure 1b). The curved corner is replaced by a rectangular one, in which static spheres accumulated due to a standing air in this area. The static spheres acted as a dynamic curved shield: When a sphere became damaged (a very slow process), it was replaced automatically and randomly by another sphere. This innovation was widely adopted.

The structure of this concept can be articulated as using an already existing object (in this case, the spheres) to carry a function of the components in the system (the shield). In this case, the solution was simple, efficient, and superior to any other previous solution, yet it took a long time for it to surface. In this article, we ask whether this type of idea, allowing for their originality and difficulty to predict, can be defined and controlled. More precisely, in our study, reported later in the article, we submitted this scenario (among other scenarios) to 40 engineers and asked them to suggest how such a system might be improved at low cost. None of the proposed concepts approached the structure of the replacement idea, described above. Yet, when a group of expert judges was asked to choose among the total set of proposed concepts (including the solution based on the replacement), the latter solution was clearly preferred. It is our contention (supported further in the study below) that although replacement-based ideas are rarely invoked by engineers, upon providing the guidelines, they are preferred due to their superior originality and value.

## Replacement Template Procedure: Illustration via Field Case

A field case involving a butter recycling process is reported to illustrate the implementation and outline a detailed algorithm of the replacement template.

### SCENARIO

In a butter-patty manufacturing process, the out-of-specification patties are recycled by placing them in a jacketed metal vat and melting them, using hot steam (see Figure 2). This conventional process is slow due to the low heat conductivity of the butter and the space between the patties (captured by air), which acts as a heat insulator. Increasing the efficiency of the steam requires further development of the current system (e.g., increasing the temperature of the steam, developing better contact between the tubes and the butter, etc.).

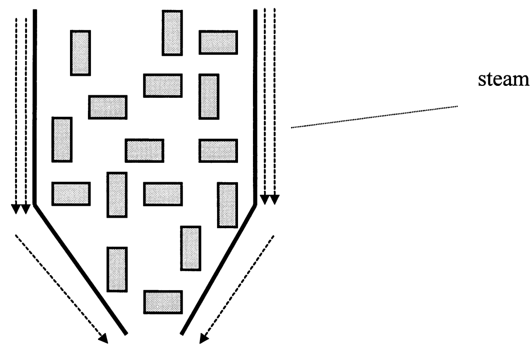


**Fig. 2. Butter patties in the vat before melting.**

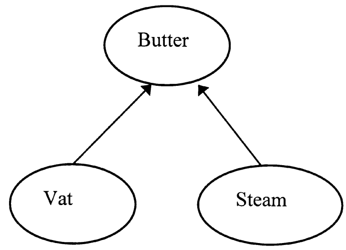


**Fig. 3. Partial configuration of the melting system.**

## REPLACEMENT TEMPLATE: A STEP-BY-STEP PRESENTATION

### *Step 1: Draw the Configuration of the System*

The configuration of the system, capturing all the necessary information for the template, is comprised by the complete set of relevant components and their (designed) functions (defined by links). A partial configuration of this system is presented in Figure 3. Components are denoted by circles and links by arrows. The vat's function is given by the link between the vat (which contains the melted butter) and the butter. The function of the link between the steam and the butter is to produce heat and transfer it to the butter to melt it.

### *Step 2: Split an Intrinsic Link and Exclude One Intrinsic Component*

In this step, an intrinsic component is eliminated from the configuration while preserving its associated intrinsic function. In the resulting intermediate configuration, this intrinsic function is not performed by any component and is termed "the unsaturated intrinsic function."

In this example, both the steam and the vat are intrinsic to the system. The slowness and lack of efficiency of the melting process is caused by the heat-transferring system (the steam) rather than the system designed to contain the melted butter (the vat). The result of applying this step on the steam is depicted in Figure 4.

### *Step 3: Assigning the Unsaturated Function to a Suitable Component*

A suitable component is defined as a readily available component (in the system or in its immediate environment) whose associated functions or intrinsic attributes are similar to those of the removed component.

Because the list of readily available components is limited, the search for suitable components can be considered as exhaustive. Normally, this search will be fairly efficient due to the constraining requirement of similarity. In our example, consider the hot milk in the first stage of the butter-manufacturing process. The similarity between the milk

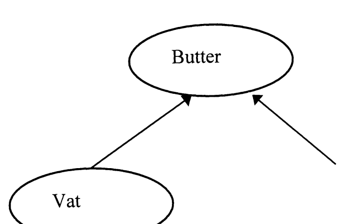


**Fig. 4. Dangling link after eliminating the steam while preserving its function.**

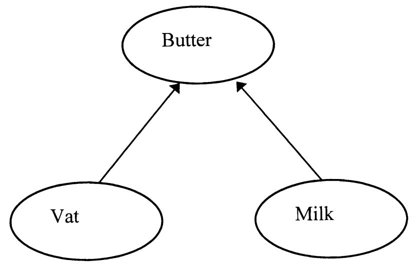


**Fig. 5. Assigning the heating function to the milk.**

and the steam lies in the fact that both of them are hot fluids. In fact, this is the only component in the environment that is similar to the (removed) steam. The assignment of the heating function to the milk results in a new configuration in which the steam's intrinsic function is now being fulfilled (Figure 5), but the steam no longer exists in the system.

According to the new idea, instead of tubes containing steam, the hot milk (from which the butter is produced) is exploited to melt the recycled butter; the hot milk can flow inside the vat and directly melt the butter. The resulting mixture of butter and milk then flows back to the beginning of the butter-manufacturing process without further changes.

By removal of the steam system, the complexity of the above technological system and its cost functions (e.g., maintenance) are reduced dramatically, the process of recycling patties is shortened due to the increase in the efficiency of the heat transfer to the butter (a direct contact between the new melting system and the butter), and time and energy costs are reduced. Technological changes such as this, although transparent to butter consumers, may serve to increase service or price flexibility, or simply improve the cost-benefit function for the manufacturer.

The presented sequence of three essential operations is defined well enough to form a Template of Innovation: By applying the template to an existing system, a new configuration is generated. The new configuration involves minimal changes from the initial configuration and (according to Altschuler, [10]) it is likely to contain an original and meaningful innovation.

## Assessing the Value of the Replacement Template to Innovative Design: An Empirical Study

To assess the relevance of the replacement template approach to innovative design, the following three hypotheses need to be supported:

*H1a:* The share of replacement-based ideas among original innovations is significant.

*H1b:* Innovators unaware of the replacement template seldom generate a replacement-based idea.

*H1c:* Replacement ideas are preferred to routine ideas.

This study is devised to address this set of hypotheses.

### METHODS AND RESULTS

#### *Are Replacement-based Ideas Dominant in Original Innovations (H1a)?*

To address this question, 100 highly original innovations in technological systems were collected using Altschuler's database and interviews with engineers in leading companies (e.g., Motorola, Scietex, Intel, etc.) in which they were asked to enumerate the most original and highly valued innovations witnessed by them during the past decade. In order to refine this database, the 100-ideas set was submitted for a judging procedure by five technology experts (senior R&D managers with more than 10 years experience, all of them had been project managers in their past). The judges were asked to grade the innovations on two dimensions—originality and quality on two 3-point scales, respectively: 3 = highly original (high quality), 1 = not original (low quality). The judgment procedure left us with a subset of 74 innovations, all of which had received a grade 3 score by all of the judges. Hence, the second (more confined) sample is postulated to consist of highly evaluated original innovations. The judges were blind to the purpose of the study and uninformed about the (replacement) template approach.

The sample of 74 innovations was then submitted to three different judges who had been trained to identify the templates of the Goldenberg et al. [12] taxonomy. The ratio between the number of replacement and non-replacement-based innovations was used to estimate the share of replacement template in original innovations.

The proportion of replacement-based innovations in the sample of highly evaluated ideas was found to be 24.3%. A test for confidence showed this ratio to be significant ($r > 15\%$, $p < 0.05$).

*Is Awareness of Replacement Necessary for Generating Replacement-based Ideas? (H1b)*

Descriptions of 12 scenarios were submitted to 380 engineers (average experience over 8 years) without specifying the innovations themselves (an average of 34 engineers for each scenario). They were then asked to propose concepts and ideas that will introduce an improvement to the system in the scenario. The instructions included a request to concentrate on innovative concepts. The 12-scenario set was then submitted to a second group of engineers trained in replacement (with similar experience, age, and occupation profile of the first group). The training included a detailed explanation of the replacement template along with examples not included in the 12 scenarios of the experiment.

The judges trained in replacement template identification examined the complete set of innovations generated by the two groups. Each concept was classified dichotomously: replacement-based versus non-replacement-based. The distributions of replacement cases in the two groups were then compared to test whether replacement ideas are spontaneously or seldom generated.

Table 1 presents the distribution of replacement-based templates in the two groups. As can be seen, the proportion of replacement-based ideas in the non-trained group is significantly lower than in the trained group (average ratio difference = 43.5%). This difference is significant for each scenario taken individually ($p < 0.01$, for the worst case) and for the average of all scenarios ($p < 0.001$).

*Are Replacement Ideas Preferred over Routine Ideas? (H1c)*

This question is partially addressed in the two studies already discussed, and in the Introduction. If this type of innovation is not easily generated, and its share in a random sample of original and highly appreciated innovations is high, then it can be concluded that the paradigm has at least some value. Simplicity and reliance on current technologies are also important designing benefits. However, to further test the proposition that replacement ideas are, indeed, preferred, the complete set of concepts (replacement and non-replacement) generated by the two groups of the previous study was submitted to eight senior R&D managers for judgment. The judges were asked to rank

**TABLE 1**
**Comparison of Replacement-based Ideas Among a Group of Non-trained Engineers versus a Group of Trained Engineers**

| Scenario | Replacement-based concepts: Without training (%) | Replacement-based concepts: With training (%) | Significance (McNemar test) |
|---|---|---|---|
| 1 | 2.6 | 52.6 | $p < 0.001$ |
| 2 | 0.0 | 62.5 | $p < 0.001$ |
| 3 | 4.0 | 32.0 | $p < 0.05$ |
| 4 | 3.7 | 81.5 | $p < 0.001$ |
| 5 | 2.9 | 79.4 | $p < 0.001$ |
| 6 | 12 | 56.0 | $p < 0.05$ |
| 7 | 6.2 | 58.0 | $p < 0.001$ |
| 8 | 0.0 | 16.0 | $p < 0.001$ |
| 9 | 4.5 | 58.2 | $p < 0.001$ |
| 10 | 3.8 | 42.3 | $p < 0.005$ |
| 11 | 4.0 | 28 | $p < 0.001$ |
| 12 | 6.8 | 75 | $p < 0.001$ |
| Total | 3.6% | 47.1% | $p < 0.001$ |

the concepts per scenario-set and sort them in a descending order of preference (in terms of recommendation for implementation). In particular, they were asked to pay attention to the success probability (according to their opinion), the risks involved, the costs, and the effectiveness of the solution. Operationally, a high density of replacement-based concepts among the top three concepts per scenario would imply preference of this type of concept.

Testing the value of the replacement template involved judging the superiority of replacement-based concepts. Table 2 shows the average priority of the concepts (per scenario). As can be seen, the replacement concepts are concentrated among the top three concepts and have higher preference for implementation. Indeed, replacement was chosen as first priority in all of the scenarios except for two (in one it came second and in the other third).[1] This preference distribution indicates that replacement-based ideas are generally perceived as superior.

**TABLE 2**
**Evaluation of the Concepts[a]**

| Scenario | Priority 1 | Priority 2 | Priority 3 | Priority lower than 4 | Number of concepts |
|---|---|---|---|---|---|
| 1 | R | n | n | n | 12 |
| 2 | R | n | n | n | 12 |
| 3 | R | n | n | n | 12 |
| 4 | n | n | R | n | 11 |
| 5 | R | n | n | n | 14 |
| 6 | R | n | n | n | 8 |
| 7 | R | n | n | n | 10 |
| 8 | R | n | n | n | 11 |
| 9 | n | R | n | n | 10 |
| 10 | R | n | n | n | 11 |
| 11 | R | n | n | n | 13 |
| 12 | R | n | n | n | 12 |

[a] The priority of implementation as recommended by the judges is presented as columns, R denotes a replacement-based concept, n denotes non-replacement based concept. The number of concepts for each scenario is presented in the sixth column.

[1] The number of concepts for each scenario was larger than 10.

## Conclusions

All three hypotheses were supported with high confidence levels: 1) The originality of replacement-based ideas was supported by the fact that only 3.6% of the individuals came up with this kind of concept. 2) The usefulness of using a replacement template as an innovation predictor was supported by the finding that 47.1% of the ideas suggested by a replacement-trained group indeed were found to be of this type of idea (and later preferred). 3) The value of replacement-based innovations was supported by the fact that in all the scenarios the replacement ideas were ranked among the top three concepts and in 10 they were assigned first priority for implementation.

Two issues regarding these results are noteworthy:

1. The replacement-based innovation is not straightforward to come up with (the average ratio in the trained group was 47.1%). However, awareness of the replacement paradigm makes it easier to detect this type of incremental innovation.
2. There might be a system with little potential to evolve according the replacement template. Obviously, in this case no replacement-based innovations will be detected by utilizing this kind of template. However the fact that 24% of the innovations in the initial sample were found to be based on replacement template justifies the usefulness of replacement in searching innovation.

## Theoretical Framework and the Rationale for the Template Approach

The rationale for the originality effect inherent in template-based inventions can be best explained by the emergence of "innovation knowledge." Figure 6 depicts the emerging recognition of innovations from the stage of latent need (Region I) to the stage of strong demand (Region II) in which the association between the need and its fulfillment by a specific change becomes transparent. The S-shaped curve is consistent with common diffusion patterns [15].

Region II offers abundant knowledge about well-developed demands. Hence, although there is a high likelihood of extracting an idea that is acceptable in that it addresses a need, it is less likely to lead to a really surprising idea (because the knowledge about the need is already diffused). In contrast, Region I represents latent need, yet to emerge as a recognized need. An idea generated in this stage is likely to be perceived as creative and, once adopted, it will trigger original innovation (because no one expects this need to be addressed). Hayes [16] defined creativity in terms of valuable consequences and novel or surprising outcomes. Accordingly, these two components of creativity are likely to be present in Region I than in Region II.

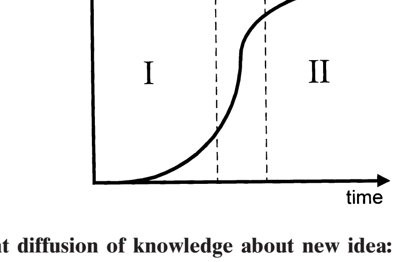


**Fig. 6. A time-dependent diffusion of knowledge about new idea: Region I, latent need; Region II, strong demand.**

A large variety of techniques (mainly in the marketing context) derive new ideas by eliciting and assessing client needs [17, 18]. Their advantage lies in their capacity to capture current needs and desires. However, such methods are mainly suitable for Region II conditions; in Region I, the information needed to satisfy measurement and validation criteria are not usually sufficient or reliable.

According to the CT approach presented here, abstract schemes that underlie ideas in Region II can be identified and applied as templates for idea generation before a demand is established (i.e., in Region I). Hence, the only information that is relatively insensitive to demand status is the intrinsic system information contained in these schemes (templates). Reliance on templates is relevant because such structures have previously occurred and have successfully governed the generation of new ideas.

The concept of using internal information to forecast innovation is consistent with some other methods. For example, the morphological analysis [19] method calls for identifying the parameters of the problem (e.g., type of ignition in cars), listing all possible combinations of parameters, examining the feasibility of alternatives, and selecting the best one. Another method involving analysis of internal parameters of the systems was suggested recently by Ulrich and Pearson [20]. Their "Product Archeology" framework focuses on predicting complex information (e.g., manufacturing costs) by analyzing existing products.

The emergence of approaches advocating that the importance of intrinsic information is at least equal to the importance of the external information has led to reconsideration of the course of events in inventive thinking process. Such a perspective is particularly useful given the traditional view of ideation as "ill-defined" (Simon [21]). The ill-defined nature of innovation prediction stands in contrast to other important management of innovation activities (such as screening, evaluation of new technologies, etc.) which are characterized as "well defined" because they lend themselves to specific definitions in terms of numerical variables and to solution plans.

Coping with the "ill-defined" nature of ideation tasks may be facilitated by an approach that is consistent with two principles. The first, originating in cognitive psychology, posits that restricting the scope of an issue enhances inventive productivity. Perkins [22] indicated that thinking within a frame of reference requires sensitivity to the rules of the game and that by functioning within such a frame, one is better able to notice or recognize the unexpected. Finke et al. ([13], page 32) noted, that ". . . restricting the ways in which creative cognitions are interpreted encourages creative exploration and discovery and further reduces the likelihood that the person will fall back on conventional lines of thought. Restricting the categories, for example, forces people to think about conceptual implications in more atypical ways, which tends to promote creative discovery . . . and can force one to consider novel interpretations of those concepts. . . ."

The second principle recommends the adoption of a structured ideation process which best mimics the thinking pattern that people follow when engaged in inventive thinking. Introspective reports in experiments conducted by Finke et al. [13] indicated that subjects often search for emergent features in the forms (e.g., images and objects), then contemplate their functional properties, imagine themselves actually using these forms and, finally, mentally elaborate on the context in which the forms should be found. This sequence of events underlies the notion of function follows form. Accordingly, people are more likely to make creative discoveries when they analyze novel forms and then assess the benefits they may project rather than trying to create an optimal form solely on the basis of desired benefits.

The usefulness of the function follows forms, in general, and the replacement template in particular, depends on the ideation context. There are cases in which the problem is not ill-defined (e.g., setting up a new enterprise to develop a new technology—the functions are already decided and the problem is to specify the best design). In this case the value of the replacement template may be quite limited. This limitation can be viewed as a result of the efficacy of well-defined problems that is consistent with the proposition of Finke et al. [13]; when constraints are imposed on functions better results are obtained than when no constraints are imposed. In such cases the replacement approach is not needed. Thus application of the replacement template is probably most appropriate in ill-defined problems (i.e., both the forms and the functions are unknown).

## Summary

A template modifies the components of a configuration and their relationships to create new benefits and innovative improvement in new structures.

The decision to concentrate on the intrinsic properties of a system is not trivial. However, limiting the scope of the problem is a necessary condition in order to find a manageable number of well-defied procedures with predictable sensible results. For an open or infinite system this would be otherwise impossible: One would encounter the frame problem being either paralyzed by the continuous infinity of factors to be considered, or having to arbitrarily choose a small subset which does not necessarily behave as a system with its own rules. The surprising fact is that the limitation of the variables of the system-space from a continuous infinity to a discrete finite number has the effect of increasing rather than decreasing creativity [13, 22, 23].

The CT approach to innovation leads to an improvement along with cost reduction before a signal for a need is sent out by clients in innovation. Finally, other templates of original designs can be identified and utilized to constitute a set of possible innovations for a specific system.

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