

Research on inherent principles of innovative design and thinking technique

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This study investigated the explanatory power and applicability of the thinking tools of SIT and other creative thinking tools through products evaluated as innovative, and proposed new and efficient integrated thinking tools for developing sustainable designs. A total of 684 Designs that were rated the best in each design awards (IDEA Design Award, iF Design Award, Red Dot Design Award) were analyzed. As a result, the inherent invention principles of innovative design were found through the explanatory power and applicability of thinking tools- a. And found the most efficient 6 thinking tools through thinking tools of various methodologies for creative products. These thinking tools are Attribute Dependency, Combination, Redefinition, Division, Analogy, and Connection. It can be said to be integrated thinking tools that can develop creative products.

Keywords: Sustainable design principles, Innovative thinking tools, New thinking tools, SIT

Introduction

A company's technological innovation and new product development are the driving force of economic growth and are a key factor in the survival and growth of companies. ¹⁸ A company's ability to launch new products is fundamental to the company's continued prosperity. ⁴ While many companies rely on 50% of their sales on new products launched over the past five years, new product development efforts often fail. ²⁷ In order for a new product to be successful, it must provide customers with a usability that is different from existing products. Creativity is essential to differentiate it from competitors' new products and is essential to the survival of modern companies in various innovation activities. ¹⁹ So, research on the development of creative thinking and sustainable innovative product ideas continued.

Brainstorming represented the principles of creative thinking that solved problems or generated new creative ideas for new products. Even now, brainstorming is a popular way to encourage creative thinking and is considered

the best way to find a list of alternative solutions to a problem. ⁵ However, some researches have shown that brainstorming is practically inefficient and ideas generated through brainstorming are no better than ideas derived from individuals. ^{5,7,20} So, several studies on the principle of systematic creative thinking about new products are being conducted. ² GoldenBerg and his colleagues proposed SIT (Systematic Inventive Thinking), which broke the thinking flow of 'form follows function', which is the main concept of modern design, and follows the thinking frame of 'function follows form'. SIT is a thinking technique that approaches accidental discovery through the process of disassembling and reassembling shapes based on five thinking tools: Subtraction, Task unification, Multiplication, Division, and Attribute dependence. ^{2,6} SIT on the basis of TRIZ insist to be more effective at generating innovative ideas than others. However, there is not enough empirical research on how much SIT have been applied to innovative designs. And not all innovative products can be explained

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with just five thinking tools. So, this study began with the hypothesis that the invention principle of innovative products will exist more than the 5 SIT thinking tools.

In this study, products evaluated as innovative were analyzed through the SIT 5 thinking tools to find the inherent invention principle of sustainable designs. And designs that are not explained by SIT 5 thinking tools were analyzed through the traditional creative thinking tools and Business Creativity Codes(BCC), which claim to complement the shortcomings of SIT. And all the thinking tools were analyzed for applicability, which is the degree of application to innovative design. Finally, based on all the analysis, we proposed new and efficient integrated thinking tools for developing sustainable and innovative designs.

Literature review

TRIZ & SIT

TRIZ is a systematic knowledge based methodology proposed by Altshuller through numerous patents analysis.²⁶ Altshuller extracted and analyzed 40,000 creative patents out of 200,000 patents. As a result, he found that the same types of problems and contradictions appeared consistently regardless of field and age, and that the same problem solving types and principles were applied repeatedly.²⁹ He summarized these common principles as '40 Inventive Principles' and developed a 'Contradiction Matrix' to utilize these inventive principles.

SIT (Systematic Inventive Thinking) was developed by Jacob Goldenberg and Roni Horowitz on the basis of TRIZ and is based on the idea that there is a common pattern in the inventive solution.⁶ Two conditions for a creative solution to appear in SIT are "CW (Closed World)" and "QC (Qualitative Change)" as follows.⁸

From 'Ideal Final Result' to the 'Closed World' condition

: TRIZ uses the following concept of 'ideality' to evaluate the solution.

$$Ideality = \frac{\sum Useful\ Function}{\sum Harmful\ Function}$$

The more useful functions and the less harmful functions, the higher the ideality. This is a very good solution if you have only beneficial features and no harmful features. In this case,

the value of ideality is infinite (∞), and this solution is called 'IFR (Ideal Final Result)'. These solutions appear when there is a problem, and disappear when there is no problem.

From 'Resolving Contradictions' to 'achieving Qualitative Change'

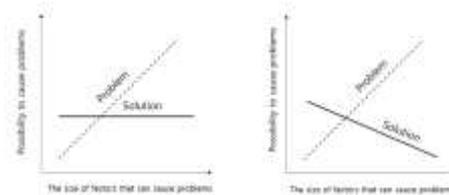


Fig. 1 _ Qualitative Change

TRIZ's "Inventive Solution" means a solution that fundamentally solves contradictions. In SIT, it's called 'QC (Qualitative Change)' when the solution doesn't affect what makes the problem worse or the relationship is reversed. That is, as the factors worsen the problem, the possibility of occurrence of the problem decreases.

SIT has confirmed that TRIZ's 40 invention principles are widely used, but there are three problems.⁸:

- The principles do not operate on a uniform abstract level
- The frequency of use is not uniform
- There are too many principles

To solve this problems, TRIZ's 40 Principles have been reduced to SIT's 5 Idea Provoking Tools by removing less frequently used principles and grouping similar principles together.⁸ Table 1 shows SIT's five ideas provoking tools.

Table 1 _ SIT's five ideas provoking tools^{2,8}

SIT	Explanation
Subtraction	Eliminate key elements rather than add functionality to the system.
Task Unification	Unifying two tasks in a single component.
Multiplication	Add one or more copies of an existing component to your product or system. The copied elements can be transformed.
Division	Divide an existing product into component

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	parts to increase the degree of freedom or reconstruct the separated elements.
Attribute Dependency	Establish or connect properties within the system or the relationship between the system and the external environment.

Traditional thinking tools

SCAMPER

SCAMPER represents a technique of forming an idea or creation designed specifically for creative problem solving and imaginative thinking.³

SCAMPER is a checklist that proposes changes to existing products, services and processes. SCAMPER is a way to get an idea by going 7 thinking tools. Rather than vaguely thinking about solving a problem, Scamper checks each item to come up with an idea. SCAMPER's thinking tools are as follows.²⁸

- S – Substitute
- C- Combine
- A - Adapt
- M - Magnify/Modify
- P - Put to other uses
- E - Eliminate
- R - Rearrange/Reverse

Synecetics and Bisociation

Synecetics is an idea method conceived by William Gordon in 1994. It is an idea method based on analogy. It's a way to discover similar things and develop ideas when thinking about things or topics.¹⁵ synectics is classified into direct analogy, person analogy, and symbolic analogy in detail. In other words, it is a method of teaching them to creatively solve problems through analogies and metaphors.

Bisociation is a method that connects two completely unrelated things. The representative method of bisociation is 'forced connection'. The forced connection method was first proposed by Whiting.³⁰ It is a method of inducing creative ideas that are used as a starting point for the idea generation process by forcibly connecting two or more products or ideas that are not related at all.

And other bisociation methodologies are Morphological Forced Connection and Morphological Analysis.

Business Creativity Codes(BCC)

SIT is based on TRIZ's 40 invention principles, and it is still focused on the technical field, so it can be said that it is not useful in fields other than the technical field, such as the business field.²² For this reason, Park extracted 10 common idea creation principles from many product and service cases and business innovation cases, and named it 'Business Creativity Code(BCC)'.²¹ Through the study of TRIZ and SIT, Park has configured the new BCC 11 Thinking Tools by adding six accidents tools to SIT 5 thinking tools. Table 2 shows BCC's thinking tools.

Table 2 _ Business Creativity Codes²¹

Thinking tools	Explanation
Redefinition	Redefine your customer's essential needs to define or differentiate your business direction.
Combination	Combine elements or functions to create usability and new value.
Connection	It creates new solutions by connecting elements that are not at all related to each other.
Reversal	Create utility and value by reversing the position, order, and attributes of important elements.
Replacement	Replace some components with others to create usability and value.
Analogy	Solve problems with inspiration from systems and processes that are different from traditional systems.

As shown in Fig. 2, BCC is complementing the SIT for use in products, services, systems, and business as well as technology by adding 6 thinking tools to the SIT's 5 thinking tools.

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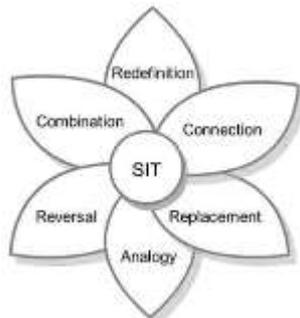


Fig. 2 _ Concept of Business Creativity Codes ²¹

Analysis of creative thinking tools through literature research

One of the objectives of this study is to discover the innovative principles of the invention that are used in conjunction with the 5 SIT thinking tools. Therefore, this analysis was performed excluding the SIT 5 thinking tools.

Literature review have found thinking tools with different names but similar uses.

These thinking tools are Combination, Connection, Reversal, Replacement and Analogy. In addition, ‘Magnify/Modify’ and ‘Put to other uses’ in SCAMPER and ‘Redefinition’ in BCC were additionally used. Table 3 shows the 8 additional thinking tools

Table 3 _ Additional thinking tools

Thinking tools	Methodology
Combination	BCC, SCAMPER
Connection	BCC, Bisociation
Reversal	BCC, SCAMPER
Replacement	BCC, SCAMPER
Analogy	BCC, SCAMPER, Synectics
Magnify/Modify	SCAMPER
Put to other uses	SCAMPER
Redefinition	BCC

Materials and Methods

Analysis Data Sources

Research data to analyze the explanatory power of SIT and additional thinking tools consists of three major design winners: IDEA Design Award, iF Design Award and Red Dot Design Award.

The analysis data is 684 designs in total for

the last 5 years (2016-2020), which are evaluated as the best in each design awards; IDEA Design Award Gold winning designs 122, iF Design Award Gold winning designs 365 and Red Dot Design Award Best Design Concept winning designs 197. ^{9,12,23}

IDEA Design Award

The American Association of Industrial Designers (IDSA), which runs the International Design Excellence Awards (IDEA), is one of the oldest and largest industrial design associations in existence, founded in 1965. The International Design Excellence Awards (IDEA) is a worldwide design competition celebrating the very best in design excellence for design professionals and students. ¹⁰ IDEA's evaluation criteria for entries are ‘Design Innovation’, ‘Benefit to User’, ‘Benefit to Client/Brand’, ‘Benefit to Society’ and ‘Appropriate Aesthetics’. ¹¹

iF Design Award

Every year iF International Forum Design GmbH organizes the iF DESIGN AWARD, one of the most famous and valuable design competitions in the world. iF DESIGN AWARD is recognized worldwide as a symbol of design excellence. ¹³ iF Design Award's evaluation criteria for entries are ‘Innovation and Elaboration’, ‘Functionality’, ‘Aesthetics’, ‘Responsibility’ and ‘Positioning’. ¹⁴

Red Dot Design Award

With more than 18,000 entries yearly from design professionals, companies and organizations from over 70 countries, the Red Dot Award is now one of the world's largest and the most renowned design competition. ²⁴ Red Dot Design Award's evaluation criteria for entries are ‘Degree of innovation’, ‘Aesthetic quality’, ‘Realization possibility’, ‘Functionality’, ‘Emotional content’ and ‘Impact’. ²⁵

Methods

To investigate how SIT is applied to innovative designs, we analyzed the explanatory power of the SIT thinking tools through innovatively evaluated products. And in order to discover the creative thinking tools used together with the SIT thinking tools, the designs were re-analyzed with 8 additional thinking tools.

The analysis method is CAT (Consensual Assessment Technique). CAT is still recognized as one of the ways creativity can be evaluated.¹⁷ Therefore, the analysis was performed according to 5 CAT procedures.¹

The 5 procedures are as follows:

First, not all judges need to have the same level of experience, but the judges should all have some experience in the field.

Second, the judges must independently conduct the evaluation.

Third, in preliminary work on developing the technique for a given task, judges must evaluate other dimensions. In this study, 'Aesthetic quality' was evaluated as other dimensions.

Fourth, judges should be instructed to evaluate the product relative to the level of the problem rather than the absolute standard.

Finally, the judges must evaluate the products in a random order.

In addition, for the high reliability of CAT, evaluation was conducted by five judges.¹⁶

The group of 5 judges who performed CAT consisted Ph.D. with SIT and BCC training, including TRIZ, and they have research experience with SIT or BCC.

This study was conducted in three steps.

First, 684 designs were analyzed to investigate the explanatory power of SIT.

Second, the designs that were not applied to SIT were analyzed as 8 additional thinking tools added in the literature study.

Third, Among the designs to which SIT thinking tool was applied, it was re-analyzed whether there were any designs to which 8 additional thinking tools were applied.

Analysis was carried out for 4 months and the consensus criterion was based on design descriptions provided by the Design Awards.

Results

Representative case analysis

As a result of analyzing 684 designs with 13 thinking tools from SIT and Additional thinking tools, 554 designs were analyzed with 11 thinking tools. 11 thinking tools are SIT 5 thinking tools and 'Combination', 'Connection', 'Reversal', 'Replacement', 'Analogy' and 'Redefinition'. 'Magnify/Modify' and 'Put to other uses' in SCAMPER were not found.

And 130 designs were not included in the thinking tools of SIT and 8 additional thinking tools. Designs that are not included in the 11 thinking tools were all included in the other dimension of this study, 'Aesthetic quality'. This reason can be found in the evaluation criteria of the Design Award. 'Aesthetics' included in all evaluation criteria.

81% of innovative designs were analyzed through SIT 5 thinking tools and 6 additional thinking tools. Table 4 and 5 show representative case analysis of SIT 5 thinking tools and 6 additional thinking tools.

Table 4 _ Representative case of SIT

Tools	Design	Explanation
Subtraction	 <p>AirPods</p>	Wires, which used to be a major component of conventional earphones, easily twisted and became a major cause of defects. By removing these lines, it is providing utility to customers. (Wire Subtraction)
Task Unification	 <p>FLAPJACK TILE</p>	Typical bathroom tiles are square, flat and waterproof. By adjusting the angle of this tile, it works simultaneously as a waterproof and object hanger. (waterproof and hanging function Task Unification)

Multiplication	<p>OZO</p> 	For VR footage, the footage had to be assembled and modified after shooting, but this product can easily create 3D footage by duplicating up to eight shutter sensors and an integrated microphone each. (shutter sensor Multiplication)
Division	<p>Leg&Go</p> 	All components are configured to be separated and reassembled. So, easily changing it into a Rocking Elephant, Tricycle, Pedal Bike, Downhill Bike or even a Polar Bike sled. (structure division)
Attribute Dependency	<p>No-Touch Timer</p> 	The no-touch timer uses an infrared sensor to detect how far your hand is from the device and convert it to a corresponding time value. The farther the hand is from the timer, the longer the time is set. (New relationship between timer and hands)

Table 5 _ Representative case of Additional thinking tools

Tools	Design	Explanation
Redefinition	<p>Relaxed</p> 	Conventional washing machines on the market are generally inconvenient for wheelchair users. This product can be conveniently used by wheelchair users by changing the height and shape of the entrance. (Redefine customers as wheelchair users)
Combination	<p>FLUX Delta</p> 	FLUX Delta is the most versatile 3D printer, which combines 3D printing, 3D scanning, laser engraving and more functions in just one machine. (Combination of functions)
Connection	<p>ENSO</p> 	Enso is a reliable bracelet shaped mask container for carrying and storage of your mask. (Connection of bracelet and mask container)
Replacement	<p>Single-Glass Triple-arch Hantile</p> 	The material of the tile used on the exterior of the house was replaced with solar panels. (Replace tiles with solar panels)
Reversal	<p>Suction Dryer</p> 	Hand dryers usually blow wind from the inside out, but this product, on the contrary, sucks in the wind from the outside. So, it is hygienic because germs that have grown by hiding in the dryer do not come out. (Reverse the direction of the wind)
Analogy	<p>Spinetec</p> 	Taking inspiration from the big femur bone in the human skeletal structure, this redistributes the existing forces more efficiently and reduces the usage of concrete and iron by up to 30%. (Analogy the human skeleton)

Explanatory power of SIT & Additional thinking tools

In this study, the explanatory power of SIT

and 6 additional thinking tools was analyzed based on the number of designs applied to the thinking tools.

259 of the 684 designs are explained through SIT 5 Thinking Tools Principles, with an explanatory power of about 38%.

295 of the 684 designs are explained through 6 additional thinking tools Principles, with an explanatory power of about 43%.

SIT and additional thinking tools, 11 Thinking Tools were applied to 554 out of 684 designs, showing 81% explanatory power.

As a result of this analysis, we identified 6 thinking tools applied to innovatively evaluated designs along with the SIT 5 thinking tools. Also, 6 additional thinking tools have been found to be identical to the BCC's 6 thinking tools.

Table 6 _ Thinking tools explanatory power

SIT	259(38%)
Additional tools	295(43%)
SIT & Additional tools	554(81%)

Applicability analysis of thinking tools

The product applicability of SIT 5 thinking tools and 6 Additional thinking tools was analyzed. 11 Thinking Tools was applied to 554 designs but the total number of thinking tools applied to the designs is 646 because there was applied more than one thinking tool in one design. These results included re-analysis through 6 additional thinking tools for designs classified as SIT thinking tools. 54 of the designs classified as SIT thinking tools were applied 6 additional thinking tools and 38 designs were used in duplicate within the SIT and Additional 6 thinking tools.

The applicability of 11 thinking tools was analyzed in the order of Attribute Dependency, Combination, Redefinition, Division, Analogy and Connection. This is shown in Table 7.

Table 7 _ Applicability of 11 Thinking tools

Attribute Dependency	129(20%)
Combination	115(18%)
Redefinition	94(14.5%)

	%)
Division	77(12%)
Analogy	67(10%)
Connection	50(8%)
Replacement	38(6%)
Subtraction	32(5%)
Multiplication	22(3%)
Task Unification	16(2.5%)
Reversal	6(1%)

Analyzing these results, the top six thinking tools accounted for 82.5% of the total. However, in these six thinking tools, only two of SIT's thinking tools, 'Attribute Dependency' and 'Division', are included. And it includes Combination, Analogy, Connection and Redefinition from 'SCAMPER', 'BCC', and 'Synectics and Bisociation'. These results show that SIT's five thinking tools cannot explain all the principles of an innovative product, and that innovative products requires additional thinking principles.

This study found the most efficient six thinking tools through the thinking tools of various methodologies for creative products. These thinking tools, Attribute Dependency, Combination, Redefinition, Division, Analogy, Connection, can be said to be integrated thinking tools that can develop creative products for sustainability.

Conclusions and Discussion

Creative and innovative new product development is essential for companies to survive. Therefore, in order to study the inherent invention principle in innovative designs, the Explanatory power of SIT 5 thinking tools and the 8 thinking tools derived from literature studies was analyzed in this study. As a result of this, we have identified inherent 11 thinking tools for innovative product. The 11 thinking tools, including the SIT 5 thinking tools, have 81% explanatory power in innovative product. In other words, using 11 thinking tools including SIT is more effective than using SIT alone and it can provide more opportunities to create innovative products.

In addition, through the applicability of 11 thinking tools, we have extracted six core

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thinking tools, an efficient and new integrated thinking tool. The Six Core Thinking Tools covered more than 82% of the thinking tools applied to innovative products.

These thinking tools are Attribute Dependency, Combination, Redefinition, Division, Analogy, and Connection. The Six Thinking Tools as integrated thinking tools are a combination of 2 thinking tools of SIT and 4 thinking tools of 'SCAMPER', 'BCC', 'Synectics' and 'Bisociation'.

In conclusion, if use six integrated thinking tools for new product development, it is effective to be evaluated as a creative and innovative product. Therefore, in order to develop innovative products, 6 integrated thinking tools must first be used.

11 thinking tools, including the SIT 5 thinking tools, are very important thinking tools for the development of creative and innovative new products. However, not all 11 thinking tools have the same degree of creativity.

Therefore, additional research is needed on the evaluation of creativity of each of the 11 thinking tools of this study. In addition, it is necessary to study commercialization of new products through 11 different thinking tools.

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