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SYSTEMATIC ANALYSIS MODEL OF INDUSTRIAL DESIGNER'S SKETCH
Descriptive study of how to read designer’s sketch systematically

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Abstract: It is known that designers employ a wide range of visual representations in order to tackle ill-determined problems that are known as the wicked problems. In addition, a sketch is typically employed among such visual presentations in the early stage of a design. Therefore, systematic analysis of the sketches that designers produce in their practice could be a means of understanding how designers think during the conceptual phase of a design. Hence, this paper explores designer sketches from two perspectives. First, preceding research concerning analyses of designer sketches that were carried out in the fields of architectural design and engineering design was extensively reviewed and analyzed. Secondly, on the basis of studies of industrial designers activities in his/her practice, methods for sketch analysis and its application are proposed. This study also structures a conceptual framework for the analysis of the sketches of industrial designers. This framework and method of this analysis will make a contribution toward a profound understanding of the characteristics of industrial designer’s ways of thinking as well as toward pedagogical applications of this work.

Keywords: industrial design, sketch

1. Introduction
One of designer’s characteristic ways of thinking is that they can skillfully employ the visualization to solve given problems. Furthermore, it can be distinguished from other specialist who focuses on verbal-analytic thinking in that they assertively use so called visual thinking in their practice [1]. In another words, designers, in their execution of given tasks, like to use diverse range of visual representation not only as a means of displaying the outcome of thinking within design process but also as the art of thinking[2]. Designers, in carrying out their tasks, build key concepts and elicit creative solutions in the early stages of the process in general, and carry out testing and evaluation of found solutions or concepts in the later stages. In consideration of such generalized behavioral patterns of the designers, it can be said that the most easily and frequently used visual representation in their early stages of design process is sketch. Therefore, in order to profoundly understand the early stages of design process in which the creative thinking of the designers are revealed most clearly, it is required to systematically analyze designer’s sketch. However, sketches are usually ambiguous in their form and ill-determined in their meaning in comparisons to other visual representations [3]. Thus they act as key factors that hinder digitalization and automation of sketches and make systematic analysis of sketch quite difficult [4].

2. Theoretical reviews
2.1. Visual thinking and Design
Numerous studies on sketches and drawings have been conducted in areas that concern visual thinking, as visualization activity is closely related to sketching and drawing behavior. Firstly, in the area of psychology, Arnheim [5] studied visual thinking in depth. He stressed
the existence of the intelligence of perception that plays the role of an active communicator with cognition in contrast with an earlier concept that emphasizes the passive aspect of perception. He viewed the drawing of a designer, that is, his or her sketch, as a creation through a mental image. He fundamentally distinguished this from the drawings of painters from models that mimic the external world. In addition, Arnheim conceives of the activity of problem solving by a designer as a cyclic behavior of mental percepts with the emphasis on the role of the sketch as a guiding image assisting the activity. Mckim [6] presented a relatively practical and explicit model of visual thinking. He holds that three different behaviors, imagination, drawing, and seeing, elicit a creative solution by interacting with each other organically; his theory explains this concept with interactive imagery. He asserted that active interactions are carried out in the area in which ‘imagining’, ‘drawing’ and ‘seeing’ overlap with each other. Rich visual thinking is manifested through such active interaction, according to this concept. An interesting aspect from the viewpoint of both authors is that they share a common viewpoint: they consider the process of visual thinking as the core process in the creative design and drawing activity, playing a significant role as a medium within this active domain.

2.2. Design and Sketch

2.2.1 Architectural design sketch

Essentially, studies of sketches in architectural design areas have been extensively carried out mostly as a supplementary role in the process of inquiring of design thinking models on the basis of cognitive studies [2]. Goldschmidt [7] analyzed the protocols of architectural designers collected in the process of observing design projects for kindergarten buildings. Firstly, she conceptually categorized the diverse range of free hand sketches produced in the early stages of the design processes. She defined this initially as a passive sketch that records and presents thoughts and secondly as an active sketch leading to and creating new thoughts. The concept is that the active sketch provides clues that are potentially significant regarding the imagery of designers through a series of repetitive and continuous changes. This enables the interactive mental image within the mental image of the human being to make creative discoveries. In addition, she asserted that the speedy yet vague, simple, varied and flexible characteristics of preliminary sketch is appropriate in containing and solving ill-defined problems at the early stages of design. Schön et al. [8] defined the design activities of an architect as a type of conversation with the working material by analyzing the verbal protocol generated by students majoring in architectural and urban planning design as well as professional designers conducting design projects for schools and libraries. Such a concept aligns with the fact that he defined professionals such as architects, designers, engineers who work in creative areas as ‘reflective practitioner’ in that their way of working can be characterized by a ‘reflection in action’ [9]. He also expressed such constructive structures of design as interactions between moving and seeing, or a design to discover and a discovery to design. Suwa et al. [3] asserted that the ambiguity of sketches generated in the early stages of design process in fact make a contribution to the improvement of the creative design. Furthermore, they, through a comparative experiment concerning professional architects and students, proved that the ability to re-interpret and re-organize ambiguous visual elements is more outstanding if the designer has relatively high expertise. A fundamental tenet of cognitive theory presumes a computational theory of the mind regarding the human cognition mechanism, in other words, the cognitive process of a human being is as the equivalent of the computational process of a machine. The presumption has the conceptual basis of the internal media of human cognition as a type of ‘languages of thought’ that can be mathematically defined. However, Goel [10] furthered this conception by asserting that the ill-structured form of visual medium, which he approximated as ‘sketch of thought’, is more instrumental than well-defined mathematical language in preliminary designing.

2.2.2. Engineering design sketch

Ferguson [11], a technology historian, has asserted an important role of non-verbal thinking, specifically visualization, in the development of engineering on the basis of his research on an enormous range of historical materials. He, by presenting a wide range of cases in which a diverse range of engineering problems that were not resolved through mathematical and analytical thinking were solved through visual thinking in the history of technology, maintained that visualization activities such as sketching and drawing by hand remain important for engineering education. In addition, he distinguished sketches into three categories according to their role. These include, firstly, the ‘thinking sketch’ drawn by engineers to think by themselves; the ‘talking sketch’ used to communicate with others, and the ‘prescriptive sketch’ for storage as drawings made for preservation and record-keeping. Such a categorization method is thought to provide a useful
conceptual foundation not only for engineering designers but also for researchers in other design domains who study sketches. On the other hand, Mazigkeitou et al. [12], while executing a project for the development of a cooperative design environment, observed an engineering team designing an attachment for a bicycle in preliminary research. The designers were video-taped and recorded as they communicated with each other, and a diverse range of sketches made during the design process were collected and analyzed. Yang [13] carried out an analysis of an idea logbook as a type of design project diary that was recorded while mechanical engineering students carried out a product development project. She quantitatively analyzed the correlations between the outcome of the design and the factors of the quantity of the design concept, the timing of the generation of the design concept, the typology of sketch, and the prior experience of the designers in engineering. This study is quite insightful in that it was carried out over a prolonged period of 10 weeks in contrast with the cognitive science-based approaches, which had a relatively short period of a four-hour experiment with verbal-oriented data collection. Moreover, it was unique in that it attempted to use the idea logbook as a source of data. McGown et al. [14] also analyzed, on the basis of the theories of Goel, a sketchbook collected from three engineering design students that were carrying out a design project. A sociological method based on qualitative analyses and traditional quantitative research methods were appropriately combined; such an approach provided insight into a more integrated analysis of an industrial design sketch.

2.2.3 Industrial Design Sketch

Although research on industrial designer’s sketch has not been sufficiently investigated compare with architectural and engineering design domain, there are some insightful literatures in the field. Tovey [4] has conducted a diverse range of research ranging from process analyses to the development of digitalized tools that assist car design on the basis of an in-depth understanding of the practical process of car design. He, in an investigation of the utilization of concept sketches within the automobile design process, concentrated on observations of the processes of six practical automotive designers and six students majoring in automotive design. He then analyzed a protocol derived from their concept sketches. He extracted fundamental factors in the sketches by analyzing concept sketches from the viewpoint of automotive design and elicited tangible differences in the methods and outcomes between the design students and the professional designers. Nagai et al. [15] conducted an experimental study to develop a model of the thinking processes in creative design. Through statistical analysis of a large number of drawings made by students as well as verbal descriptions that had been written on the drawings, they explored how verbal concepts and visual images interact within the process. They eventually constructed a model describing how creative visualization is made. Despite differences in the domain-specific contents and methodology between different areas of design, there was common acknowledgement that the role of a sketch is not only a visual display that simply expresses the outcome of thought but that it is also an effective means of creative problem solving in the conceptual stage. Hence, the employment of visual representation in his or her problem solving is thought to be a characteristic behavior that only a designer possesses.

2.3 Alternative analysis methodology

This chapter aims to establish a conceptual framework for systematic analyses of the sketches of an industrial designer on the basis of prior studies. The process of systematic sketch analyses can be divided into the collection process and the analysis process for more profound investigation.

2.3.1 Sketch collecting process

The collection process of industrial design sketches with the consideration of the analysis methods attempted in other design domains and the unique characteristics of industrial design can be divided into two parts from a temporal perspective: short-term sketch collection and long-term sketch collection. Short-term collection is the method most often applied to the architectural design research. It is the method of collecting sketches that are created during the execution of tasks by designers over periods of 1-4 hours on the basis of the think-aloud technique. Here, the overall design process is verbally described during the execution of the design task [16]. However, the verbal description of the designer during the process actually defies creative thinking, and there are high artificialities in doing design task within a relatively short period of time [17]. On the other hand, long-term sketch collection involves the extensive collection of the sketches produced in design processes carried out over periods of several days or weeks in the actual studio environment. Such an approach has the disadvantage of involving an enormous amount of data and has the risk of subjective decision-making by the researcher during the data-collection process. From a spatial perspective, it may be divided into laboratory-based collections and workplace-oriented collections. Laboratory-based collections are based on the technique of
experimental psychology. In general, various measurement and observation apparatuses are installed in a laboratory for efficient data collection and the designer, as a subject, participates in the design. With such a method, although it is effective in extracting quantitative data as control of variables is accomplished with ease, there are numerous highly artificial factors generated from environment and apparatuses in comparison to real-world design condition. Accordingly, questions concerning the appropriateness of such experiments are raised continuously. In contrast, workplace-oriented collections are based on the methods used mainly by anthropologists or sociologists. Collection of vivid and abundant data is carried out by having the researcher personally come into contact with designers by entering the actual studio in which the designers work. However, it has been pointed out that with this method, it is difficult to in secure the objectivity and clarity of the data collected.

![Figure 2.2. Formal vertical and horizontal transformation](image)

![Figure 2.3. Functional transformation](image)

### 2.3.2 Sketch analysis process

The sketch analysis process subsequent to the collection process can be further divided into 'formal analysis' and 'functional analysis' depending on the type of data. Formal analysis was attempted in research by Goel [10] in his analysis of architectural design sketches and graphic design sketches. If a diverse form of a sketch is generated, it is defined as a lateral transformation of a sketch. In contrast, if it progresses in depth while maintaining a similar look, it is then defined as a vertical transformation [Fig. 2-2]. As changes in the form of the sketch are clearly revealed externally, comparisons and analyses are relatively easy. In contrast 'functional analysis' refer to observation of change in meaning and function that sketch is presenting. Functional analysis is thought to be an appropriate approach in the analysis of an industrial design sketch in that, a new function or meaning needs to be proposed in the early stage of industrial design unlike architectural or engineering design having pre-determined subject matters e.g. a house, bridge, a brake system and so on. Fig. 2-3 shows a sketch that illustrates an example of functional analysis. Although two sequential sketches have common formal aspect, i.e. bellows structure, relatively explicit functional difference in sketch development from 'fan' to 'umbrella' is observed. The analysis process of the sketch can also be subdivided into a 'qualitative analysis' and a 'quantitative analysis' according to the type of analysis method. First, the 'qualitative analysis of a sketch focuses on the discovery and explanation of a specific phenomenon observed in the sketch of the designer rather than verification of proposed hypothesis. Basically, systematic quantitative analysis in sketch study is conducted with coding schemes, that is, deductively defined classification rule, and a retrospective interview with the designer who made sketches. On the other hand, a 'quantitative analysis of a sketch is based on statistical methods. It aims to verify the hypothesis established to find various relationships among variables derived from designer’s sketches (Yang [13]).

![Figure 3.1. Sketch collection (L) and analysis(R) framework](image)

### 2.3.3 Framework for sketch collection and analysis

In this chapter, the conceptual framework of a sketch analysis is structured on the basis of the aforementioned viewpoints. Fig. 3-1 depicts the representative studies of the architectural design sketches, engineering design sketches that were reviewed earlier in this framework. It can be seen that the area of architectural design research on sketches is relatively broadly distributed throughout the frameworks. Although it is somewhat concentrated on the short-term collection method, it has a wide spectrum. Studies by Ferguson [11] can be seen as functional analyses from a macro perspective considering the role and significance of sketches within the overall design process rather than a microscopic analysis of the sketch. In the context of engineering design, determination of functions is generally pre-made, due to the hierarchical characteristics of engineering project. Thus its focus has often been placed on
the diverse range formal exploration on the basis of functional determination. Hence, the tendency for a quantitative and formal analysis rather than a qualitative analysis appears to be strong. Regarding sketch collection, the technique of observing the sketch of a designer over the long-term has been applied in, for example, the use of the idea log book. However, the approach of Maziejglou [12] was a laboratory-based project conducted over a short period of time; the study concentrated on observation of the communication and relationships between team members through the interaction of the sketches rather than focusing on the sketch itself.

3. Plausible analysis model

3.1 Collection of industrial design sketch

Assertions of architectural design researches (Lloyd et al. [17] and Do et al. [18]) point out the limitations of the existing approaches based on their short-term based and rigorous lab-oriented conditions and give following implications. First, the conceptual stages of the industrial design process, unlike laboratory-based research, does not occur within 1-4 hours. Although there are differences among the types of projects, in general it is carried out over a period of several days and as such must be sufficiently considered in the sketch collection process. Secondly, the viewpoint that design behaviors can be observed as a social activity (Bucciarelli [19]) needs to be reconsidered. Although, in the majority of situations, the conceptual stage in the industrial design process is carried out individually, active social interactions always occur in design studios, which are the main work spaces of industrial designers. According to relevant studies, designers acquire more information and knowledge through a diverse range of informal media; e.g. casual conversation or talking with colleagues compared to formally established design libraries or databases (Wallace [20]). Furthermore, a single designer is often tasked with multiple design projects concurrently. In such cases, it is the reality that the ideas of different design projects that are being executed simultaneously influence each other. Therefore, the collection process of an industrial design sketch must be devised with sufficient consideration of this industrial design context. In conclusion, a long-term approach from a temporal perspective and a workplace-oriented collection from a spatial perspective appear to be appropriate for an industrial design context [Fig. 3-1]. Such an approach is similar to the methods attempted in sociology and anthropology and is based on the type of research that requires observation of industrial designers in the workplace for a prolonged period of time. In line with this, the idea logbook method used in engineering design research, as mentioned earlier, is deemed to be an appropriate tool for application in collecting industrial design sketches. That is, the behavior of an engineer informally recording novel ideas appears to be quite similar to the ubiquitous activity of an industrial designer doodling on a sketchbook in the conceptual stage of the project. It could be an alternative that will enable abundant and effective collection of industrial designer sketches that are drawn over prolonged periods of time in their environment. The conceptual groundwork underlying the industrial design sketch collection is illustrated in [Fig.3-2]

![Figure 3-2. Industrial Design Sketch collection (L) and analysis(R) framework](image)

3.2 Process for collecting industrial design sketch

For a solid establishment of a systematic sketch collection model on the basis of aforementioned investigation, a practical stepwise collecting process for an industrial design sketch can be described as follows; First Stage: Distribute a sketchbook to the industrial designers currently conducting the project by visiting the studio, the workplace of the industrial designer. The sketch recording methods can be considered as similar in perspective to those of the diary recording methods used in sociology and anthropology in order to supplement the subjectivity and ambiguity in a collection of anthropology data in workplace-oriented and long-term collection environments [21]. Second Stage: Instruct the designers to use the sketchbook with the date on each page while doing their project. The marked date serves as a temporal reference in observing the context of changes in the sketch during the analysis process. Recording of the sketchbook can be thought of as an extremely casual and natural behavior in consideration of the fact that thumbnail sketches are pervasive in their everyday lives regardless of their workspaces and media. As the sketchbook of the designer may contain a diverse and rich range of situations that designers experience in daily life in addition to
thumbnail sketches, it is believed that the sketchbook can provide a rich and fresh resource for analyses and understanding of sketches. Third Stage: The industrial designer is asked to arrange the recorded sketch in serial sequence. A conceptual sketch, which has been sequentially arranged, is useful in assessing the mutual relationship and context of images at a glance for the subsequent analysis.

3.3 Analysis of industrial design sketch
The analysis process of a sketch also requires understanding of the characteristic viewpoint that only industrial design possesses, as distinguished from other design domains. In the case of architectural design, the basic functional premise of the creation of a living space has been somewhat determined. In the case of engineering design, the target function has been pre-structured in advance through a technical specification. Thus, a diverse range of variation in geometry processing technique are subsequently attempted in order to satisfy this. From this perspective, the research of Goel [10], as mentioned in the previous chapter, is evaluated as having presented the fundamental steps for designer's sketch analyses as it proposes that the qualitative changes observed in architectural designer sketches are placed into two categories: lateral transformation and vertical transformation. On the other hand, McGown et al. [14] who researched the mechanical engineering designer's took theories of Goel [10] as groundwork for the analysis of their design sketches and added the analysis factor of complexity. He attempted to quantify the result of analyses of sketch books that engineering designers recorded. The concept of complexity indicates a phenomenon that similarly appears in industrial design sketches. The more an industrial designer generates diverse and rich ideas in the sketchbook, the more complex the sketches in the sketchbook become. This displays the tendency of visual complexity. Hence, not only the concept of vertical and lateral transformation derived from Goel, but also the notion of complexity raised by McGown et al. is thought to be considered in the analysis of an industrial design sketch. The concept of 'reflective transformation' as a novel factor to be considered in the analysis of an industrial design sketch in addition to the analysis factors used in the research of an architectural design sketch and an engineering design sketch will be defined. Reflective transformation theoretically stems from the idea of a 'conversation with the sketch' asserted by Schön and the idea of 'dialectics of the sketch' of Goldschmidt. In other words, designers often experience a type of non-linear process in which the sketch that had been passed in the mid-stage is reused as the final proposal instead of sequentially developed sketch in the process of a conceptual stage. This implies a situation in which the designer undergoes reflection of thought by looking back at the sketches he or she had drawn, and re-interpreting sketches that was given up in the past for a new conceptualization. In summary, it appears ideal that formal analyses as well as functional analyses be considered in accordance with the analysis factors for the industrial design sketch; both qualitative and quantitative methods are required to be executed in balance in accordance with the types of analysis targets. In particular, the approach McGown et al. applied in an engineering sketch analysis is found to provide a useful foundation for research into industrial design sketches that integrate qualitative and quantitative perspectives in balance in a sketch analysis. A summary of the analysis framework of an industrial design sketch is illustrated in [Fig. 3-2].

![Figure 3-3. Divergent sketch by BoKum, Foster and GRO design](image)

![Figure 3-4. Convergent sketch by Chrysler and Seo](image)

3.4 Process for analyzing industrial design sketch
The analysis process is necessary after having collected the sketches of an industrial designer through the sketchbook. Among the diverse range of analysis perspectives mentioned earlier in this paper, the following three issues can be used as a key coding scheme for an industrial design sketch analysis. First, if the intention of the industrial designer is diversification of form and structure in order to find solutions to given problems and if this is presented in the sketch, it will be defined as a divergent sketch [Fig. 3-3]. This is a concept similar to the lateral transformation that Goel [10] defined. Secondly, if the action of an industrial
designer that deepens the idea by staying with the current concept is visually revealed in the sketch, this is denoted as a convergent sketch. For example, this refers to the situation in which the activities of adding detailed elements or elaboration e.g. parting lines, graphics or shadings to the present design as shown in [Fig. 3-4]. Thirdly, if a sketch that was drawn previously is reutilized, it shall be defined as a reflective sketch. A similar concept was used in verbal protocol analysis of an engineering designer by Valkenburg et al. [22]’s literature to explore the attributes of reflective practitioner in engineering design activity. Fourth, the concept of complexity of the sketch is employed to analyze an industrial design sketch. This was mentioned previously and signifies the visual complexity presented in the sketch. In the case of an industrial design sketch, it appears that a relative distinction at a three-point scale within a single page of the sketchbook would be realistically possible, as the style and presentation methods are highly varied depending on the designer. Underlying framework of industrial designer’ sketch can be summarized as [Fig. 3-2].

3.5 Visualization of sketch analysis

3.5.1 Role of visualization on analysis results

A complex and large amount of sketch data collected and the outcome of its analysis can be processed to enable it to be seen at a glance through appropriate visualization method. In other words, it is possible to assess the pattern, tendency and relationship of the changes in a sketch efficiently through a visual representation, and it also would be possible to mutually compare or juxtapose designers systematically on the basis of this assessment.

3.5.2 Sketch Activity Matrix

In order to visualize the outcome of an analysis on industrial design sketches most appropriately, the four factors; the convergent sketch, the divergent sketch, the reflective sketch and the complexity, appear to be necessary to take into account efficiently. Accordingly, a method to visualize insightfully the qualitative and quantitative status of the sketch at the corresponding stage as well as display the level of complexity of a sketch in accordance with the progress of the design is necessary. Hence this study aims to propose an effective means of visualizing the outcome of the analysis of the sketch of an industrial designer through the introduction of a 'Sketch Activity Matrix'. The sketch activity matrix utilizes rows, columns and dots. The columns represent the pages of the sketchbook. Essentially, they can be considered as the number of pages of the sketchbook used by the designer. On the other hand, the rows represent the number of independent items embodied on the corresponding page by the designer. In addition, the sizes of the dots at every element of the matrix refer to the complexity of the item. The complexity from beginning to the completion of the conceptual sketch can be illustrated with three different sized dots by linearly interpolating from the simplest level to the intermediate level and the most complex level. Lastly, it is important to indicate the relationship between design items. Items that exist on the same row indicate that sketching is being performed sequentially through ‘convergent thinking’, as mentioned earlier in the previous chapter. Hence, it signifies items for which gradual improvement is occurring without changes of the design direction. On the other hand, a wide spread of the same column implies that the sketch is being developed through 'divergent thinking'. With 'reflective thinking', this can be expressed through the return of the sketch to a row through which it has already passed. In other words, it refers to the phenomenon of returning of ideas previously deployed through divergent thinking as a better idea.

[Fig. 3-5] shows an example of the sketch activity matrix. This designer conceptualized three items on the first page of the sketchbook and another three on the second page. However, one of the items drawn on row C on the second page appears to be an extension of an item on the first page. As the concentration has gotten deeper, it appears that the first item was further developed with increased complexity and more detail through convergent thinking. Until page 3, divergent thinking predominates, but from page 4 on, convergent thinking reoccurs. It should be noted that the item drawn on page 4 has returned to the item already drawn on the same line on the page 1. That is, although the designer repeated divergent thinking until page 3, eventually the designer decided that the item on row C in the first page would be the final solution and concluded the
concept sketch through convergent thinking up to page 6. For a more objective interpretation of the particular situations in each sketch, post-interviews can be employed as a type of studio presentation or critique. Consequently, the sketch activity matrix method is devised with consideration of the aspects discussed below. First, sketch activity at the conceptual stage that is implemented in industrial design practice is holistically explored and a matrix is structured on this basis. The ubiquity of the thumbnail sketch culture of an industrial designer was profoundly considered in order to put effort into the analysis of the conceptual sketch through a more systematic framework. Attempts are made to accommodate the unique sketch patterns of an industrial designer as distinguished from an architectural designer making large-scale drawings or an engineering designer producing a well-defined diagrammatic visual. Secondly, the sketch activity matrix is focused on interpreting and understanding the outcome of a sketch analysis with more intuitive and an easier technique. Hence, it was devised to propose a conceptual framework that even sketch instructors in educational institutions can employ intuitively to analyze and evaluate sketches made by their students. In addition, it is anticipated that the realization of a computational evaluation system on sketches can be possible if a relatively simple algorithm structure is combined with computer vision recognition technology. Thirdly, sketch activity is expected to play a supplementary role in existing design research methodology in that research on design thinking, which has been carried out with emphasis on architectural design and engineering design areas, are concerned the analysis of verbal data from think-aloud techniques under the control of an artificial lab environment; the majority of non-verbal and visual data including gestures or visual representations have been considered to supplement think-aloud data. Furthermore, in-depth research on the sketch activity of designers has been focused more on architectural designs or engineering designs rather than industrial designs. Hence, the research context also differs from that used with industrial design. From such a perspective, analyses of the results as visualized through the sketch activity matrix with the sketchbook of an industrial designer as the medium is thought to be significant in that it will supplement existing verbal-oriented research methods. Moreover, it proposes a new means of interpreting the outcomes of design thinking research.

3.6 Application and evaluation
This chapter analyzed a sketchbook recorded by the industrial designer S, an imaginary name, who carried out a project on the basis of the aforementioned methodology. The study attempts to visualize the result of the analysis through the sketch activity matrix. A conceptual sketching was carried out over a period of one week with two intermediate presentation meetings. A post-interview was conducted and recorded through a presentation meeting, and it was used as a reference material in assessing the context and relationships between sketches. The design task was ‘designing household products using extruded aluminum material’. Through this project, the designer, S, produced a total of eight conceptual sketches and one final rendered design. [Fig. 3-8] illustrates the sequential arrangement of conceptual sketches.

![Figure 3-6. Divergent and convergent sketch by designer S](image)

![Figure 3-7. Reflective sketch by designer S](image)

![Figure 3-8. Sequential arrangement of conceptual sketches](image)

The sketch on the left side in [Fig. 3-6] illustrates the typical development of the divergent sketch. It can be seen that the form of the several small pipes with different heights that are tied in a bundle has been changed into the form of small holes in a single large cylindrical pillar. The sketches on the right are displaying typical convergent
thinking. After producing an experimental form and structure intertwined with small pipes by sketching various straight lines, one pattern was obtained. In the next stage, a conceptual sketch was completed by presenting the form of tableware being displayed in detail. [Fig. 3-7] exemplifies the reflective sketch. The sketch with the form of irregularly intertwined small pipes was an item that previously appeared on page 1 for the first time. It did not appear for some time until page 6, thereby illustrating the process of determination of this item as the final proposal. In addition, the item with form of small holes in a single large circular pillar is also a form that appeared on the second page. It was observed that no further development occurred for this design, as it remained in a discontinued state, until the fifth page where it reappeared. [Fig. 3-9] visualizes an overall view of idea sketches of industrial designer S through the sketch activity matrix after an analysis of each stage. It can be observed that divergent sketches that signify divergent thinking are predominant. However, divergent sketches up to page 4 display a tendency of gradual reduction with eventual changes in the main flow into convergent sketches. Furthermore, the gradual enlargement of dot size in the matrix illustrates that the complexity of the sketch is gradually increasing. Such a tendency indicates that the industrial designer at the early stages of the design produces a diverse range of ideas relatively freely and broadly. The designer then gradually focuses on convergent thinking more so than divergent thinking with the consideration of the design limitations and conditions. In addition, the complexity of the sketch in this progress increases naturally. As mentioned above, the diverse range of ideas rapidly increases quantitatively within a short period of time on pages 1 and 2. The reflective thinking, which is the process of scrutinizing past solutions in order to elicit a new design solution in the event of failure to find a satisfactory solution from the existing concepts that were developed sequentially for the problem, is observed from page 6. The complexity of the sketch reaches the highest level when solution is decided upon through a reflective sketch and the conceptual stage of the design is completed. Accordingly, the sketch activity matrix can systematically and simply illustrate the complex analysis results on a diverse range of idea sketches that are produced in the conceptual stage by industrial designers through a visualization method.

4. Conclusion
The analysis framework for an industrial design sketch elicited in this paper clarified the conceptual difference in his or her working context between other design domains and the industrial design; at the same time, it proposes the appropriate approaches required to take into account the analytic perspective of a sketch. Furthermore, the sketch activity matrix has enabled relatively systematic and intuitive visualizations of the outcome of analyses of the sketch of an industrial designer.

![Figure 3-9. Sketch activity matrix](image)

Studies on industrial designer's sketches thus far, due to the focus placed on the somewhat mysterious and sensual aspects of the sketches, remain at the level of an artistic style analysis while training technique or tend to concentrate on hasty automation or digitalization of the sketch process by excessively emphasizing its objective and scientific aspects. From this perspective, this research has two significance contributions. First, it is believed that the factors of industrial design sketch analyses and the sketch activity matrix as proposed in this paper provide an instrumental guide to industrial design education. These outcomes can be employed in facilitating and supporting systematic evaluations and analyses of idea sketches made by industrial design students as well as in acquiring design expertise, which has been emphasized by investing substantial time and resources in training technical skills thus far. Secondly, this study provides useful instrument from the perspective of design theory research. Verbal protocol analysis method applied in laboratory experiment has been highly favored for use in exploring how designers
think. To the contrary, visual representation including designer's sketch and drawing made from a macroscopic view has not been sufficiently investigated. In this sense, the intensive investigation of the collection and analyses methods of visual data is expected to provide a more profound and balanced viewpoint in the theoretical study of design activity. However, this research continues to require a more solid structure that encompasses not only the formal transformation factors of industrial design sketches but also the functional transformation factors, particularly in the application of the sketch activity matrix. This is an area for further study. Furthermore, in order to receive broader validity and practicality, a wider range of quantitative experiment along with further workplace experiments are necessary.

5. References

1. Tovey M. Designing with both halves of the brain. Design studies 1986; 7(1):20-30