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Problem-Solving Model of Design
With a Controllable Determinization[1] Level

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1. Introduction

There have been a great number of preceding studies which interpret design in two paradigms: rational problem-solving relating to positivism and reflection-in-action which is connected to constructionism (Dorst & Dijkhuis, 1995). Rational problem-solving as suggested by Simon (1996) is a design process which emphasizes the analytic aspect of design activity, while reflective-in-action as proposed by Shön (1983) is a design activity which indicates the restraints of technical rationality and illustrates the importance of the synthetic aspect of design activity.

Many researchers have compared the two different paradigms (Dorst & Dijkhuis, 1995; Fricke, 1999) or have emphasized one paradigm over the other. While there have been various attempts to scientifically decompose design problems or solutions (Findler, 1981; Newell & Simon, 1972; Oxman, 1986; Simon, 1996) and construct logical linear design processes, there have conversely been various studies that compare the two paradigms and display the limitations of the 'problem-solving approach' (Akin, 1990; Holt, Radcliffe & Schoorl, 1985; Jonas, 1993).

However, many studies that place an emphasis on one paradigm or make a comparison between the two paradigms fail to produce a model that not only embraces both paradigms but also satisfies the "wicked" property of design problems (Rittel & Webber, 1973). Moreover, a research about the interaction between the solution structure and design process is an important issue to explore (Joseph, 1996; Simon, 1996).

The objective of this study is to suggest a problem-solving model of design which supports both paradigms of design activity and correlates solution space with process by devising a determinization level that controls

[1] The words 'determinize' and 'determinization' are defined in this paper as follows:

"determinize": to transform the indeterminate state into the quasi-determinate state

"determinization": the act or process of "determinizing" or reaching a quasi-determinate state the degree between analytic and synthetic aspects according to the different design conditions.

In Section 2, the property of the subject matter of design is explained and compared with that of science, and the term 'quasi-determinate', a new concept that describes the property of the subject matter of design is introduced. In Section 3, a problem-solving model of design is proposed and each part of the model is explained. In Section 4, examples were illustrated to explain functioning of the model suggested in Section 3. Finally, in Section 5, a conclusion and further study related to the proposed model are described.

2. Property of the Subject Matter of Design

It has been argued about what the subject matter of design is and what its properties are since the early era of design research. Many former researchers (Alexander, 1964; Buchanan, 1995; Cross, Naughton & Walker, 1981; Cross, 2001; Gregory, 1966; Simon, 1996) in design agreed with the idea that the subject matter of design is different from that of science. The subject matter of science is given, such as nature, while that of design is not given; that is to say, it is artificial (Bayazit, 2004; Buchanan, 1995; Cross, 1982; Cross, 2001; Simon, 1996). The property of the subject matter of science is determinate, therefore the proper approach toward science is a scientific approach; or more precisely, to 'discover' (Buchanan, 1995; Dorst & Dijkhuis, 1995; Jonas, 1993). On the other hand, the property of the subject matter of design is indeterminate, therefore the appropriate approach to design is a non-scientific approach, to 'invent' (Alexander, 1964; Buchanan, 1995; Cross, 1982; Cross, 2001; Gregory, 1966; Jonas, 1993). Owen (2005) introduced 'the Two-Domain Creativity Model', which is divided into 'discovery' and 'invention'. 'Discovery' is oriented toward 'analysis', and those who work in this way are known as "finders". 'Invention' is oriented toward 'synthesis'; those who work in this way are known as "makers" (Owen, 2005). The two different approaches, both related to Tovey's (1984) 'dual processing model', are based of the two different roles of the left and right hemispheres, 'analysis' and 'synthesis'. Also, in 'Knowledge usage in new product development(NPD)', Rodgers et. al.(1998) classified knowledge used in design in several terms, and among various types of knowledge, explicit or algorithmic knowledge are related to 'discovery' and tacit or heuristic knowledge are connected to 'invention'. In addition, while the evaluation criteria of science are 'true/false' or 'complete/incomplete', that of design is 'good/bad' (Cross, 1982; Owen, 2005; Simon, 1996).

When looking back upon the history of the efforts in "scientising design" described by Nigel Cross (2001) the subject matter of design research has changed over three eras. In the 1920's, the subject matter of design research that design methodologists tried to scientise was mainly focused on 'product', which are the solutions in a problem-solving process of design. In the 1960's, the subject matter of design research shifted from 'product' to 'process', which corresponds to problem-solving (process), and design methodologists began focusing on scientising the 'process' of design research rather than the 'product' of design research (Bayazit, 2004; Cross, 2001; Dorst & Dijkhuis, 1995). In the 1980's, many design methodologists agreed that the property of the subject matter of design including both 'product' and 'process' is indeterminate. Nevertheless, they converged on the idea that even though the property of the subject matter of design is indeterminate, the approach to the indeterminate subject could be scientific (Archer, 1991; Cross, 2001; Jonas, 1993).

When scrutinizing the match between subject matter and approach, in the 1920's design methodologists regarded 'product', which is a solution, as a determinate subject matter and matched that with the scientific approach. The match between the property of the subject matter and the approach in the 1920's is well-matched by matching determinate matter with the scientific approach. However, as was revealed in the 1980's, the property of design 'product' is not determinate but indeterminate, and therefore demonstrates that the attempt in the 1920's was wrong. In the 1960's, design methodologists considered the 'process' of design, which is a form of problem-solving (process), as a determinate factor, and applied the scientific approach to it. However, like the 'product' of design, the 'process' of design is also indeterminate, consequently the hypothesis in the 1960's was also wrong. In the 1980's, although design methodologists found that the property of the subject matter of design is indeterminate, they matched the indeterminate subject matter with the scientific approach. The match between the subject matter and this approach is actually a mismatch, hence the need for a new approach to design research that correctly matches these two factors is required.

There are two ways to match these two factors correctly. One is to discover a non-scientific approach for the indeterminate subject matter, and the other is to find a determinate area in design research. Regarding the former method, many design researchers, such as Shön (1983) and Petre (2004) have offered various methods for creative thinking, but have not been able to suggest definite non-scientific methodologies for design research. In this study, however, the latter perspective is applied. In design research, 'solutions' and 'problem-solving' are indeterminate, but 'problems' and 'goals' are determinate within a certain extent. In this study, the property of problems and goals is termed "quasi-determinate".

In the existing design research, the subject matters of design research are 'solutions' or 'problem-solving' which were described as 'product' and 'process', respectively, by Nigel Cross. These subject matters are indeterminate and therefore a non-scientific approach, such as 'reflective-in-action' by Shön is applicable to them. In this study, 'problems' and 'goals,' which are quasi-determinate, are regarded as subject matters of design research, focusing especially on 'goals'. Unlike 'solutions' which are indeterminate, 'goals' are determinate to a certain extent and, within a determinate boundary, they are indeterminate. The property of 'goals' can be illustrated as being similar to the 'molecular movement of gas'. Gas moves randomly in a fixed form, but the movement is restrained within that fixed form. The 'fixed form' is connected to the determinate boundary, and the random movement of gas indicates the indeterminate property of goals.

Because 'goals' are quasi-determinate, scientific methods such as 'discovery' can be applied to them; for the determinate boundary, scientific approaches are applicable while inside the determinate boundary, non-scientific approaches such as methods for inventing and creating should be applied. The fact that there are certain areas in design research which can be scientised supports the possibility of a design discipline which can be universally valid and understood.

3. Problem-Solving Process of Design

3.1 Goal versus Solution

The principal differences between 'solution' and 'goal' in design research are that 'solution' is indeterminate and is about 'what' while 'goal' is "quasi-determinate" and is about 'why' or 'for what'. A goal, the 'why' or 'for what' factor, is more closely related to 'purpose' or 'objectives' (Dorst & Dijkhuis, 1995; Nadler, Smith & Frey, 1989); while a solution, the 'what' factor, is related to the 'outcome' or 'result'. In the 'model of a problem space' (Newell & Simon, 1972), the goal state is described as a representation of the solution to the problem (Middleton, 2005). A goal is the central pivot of various possible solutions. For example, in this author's elementary school era, dentists visited the school and taught the students how to brush their teeth correctly. They taught the students that the right way to do this was to brush from the roots of the teeth. Growing up eventually led to the realization that the food dregs left between the teeth caused the teeth to decay. After discovering the cause of decaying teeth, flushing, gargling, the use of toothpicks, or brushing between the teeth to remove the dregs from the teeth followed. In this example, 'bushing from the roots of the teeth' is the 'solution', 'the decayed teeth' is the 'problem', 'removal of the dregs left between the teeth' is the 'goal', and various possible solutions tied to the goal are 'flushing', 'gargling', 'brushing between the teeth', and 'using toothpicks'. 'Brushing from the roots of the teeth' is also still a 'solution', but it is one of many possible solutions. If children did not realize the goal of the solution, although they brush from the roots of their teeth and succeed in following this guideline, they may fail to remove the dregs from their teeth. However, if children acknowledge the goal, they would not only brush their teeth from the roots in consideration of the goal to remove the dregs from the teeth, but also use other effective ways to resolve this problem. The 'Goal' is about resolving the problem, while the solution is one of several possible solutions that solve the problem.

The distinction between goal and solution is connected to a generic problem-solving framework in the TRIZ(Teoriya Resheniya Izobreatatelskikh Zadatch) which is the Theory of Inventive Problem Solving(Mann, 2001) (shown in Fig. 1). The "generic" problem and solution supports the necessity of the goal-oriented problem-solving model.

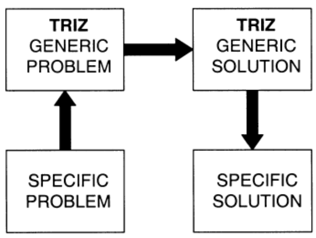

Figure 1. The TRIZ Process

3.2 Problem-Solving Model of Design

The proposed problem-solving model of design is a goal-oriented model which distinguishes a 'solution' and a 'goal' and transforms the binominal relationship between a problem and solution/goal (shown in Fig. 2) into the triad relationship among a problem, solution and goal (shown in Fig. 3). As described in the previous section, goals are 'quasi-determinate'; therefore the problem-solving model of design as shown in Fig.3 can be divided into two parts: a quasi-determinate part and an indeterminate part. Concerning each part, different approaches can be applied respectively; toward a quasi-determinate part, the 'problem area' and the 'goal area', a scientific approach of 'discovery' (Jonas, 1993), and toward an indeterminate part, the 'solution area', a non-scientific approach of 'invention or creation'.

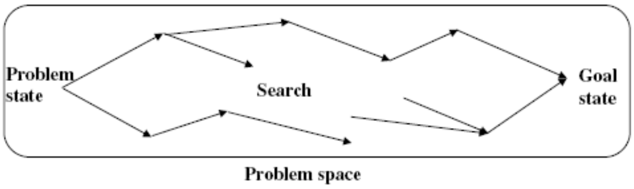

Figure 2. Model of a problem space (Newell & Simon, 1972)

In 'Wicked Problems in Design Thinking', Buchanan (1992) described a linear model of a design process to explain the limitations in the linear model for "wicked" problems of design. The 'problem definition', the analytic sequence in the linear model, is related to the 'quasi-determinate' part – the 'problem area' and the 'goal area' in this paper, and the 'problem solution', the synthetic sequence in the linear model is connected to the 'indeterminate' part – the 'solution area' in this study.

Buchanan (1992) asserts that the limitations of the linear model for wicked problems of design are based on determinate problems while the wicked problems relate to indeterminacy, indicating 'indefinite conditions or limits'. However, in this paper the limitations of the linear process are overcome by suggesting the concept of a determinization level of goal area that flexibly controls the design process according to various conditions.

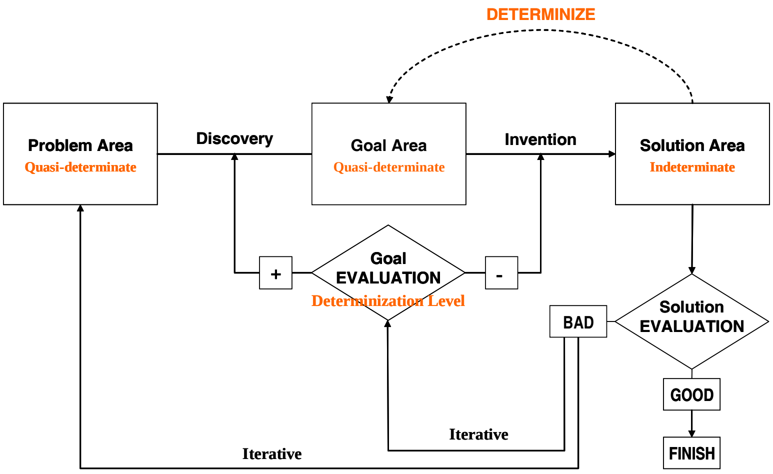

Figure 3. Problem-Solving Model of Design

The procedure of the design follows. First, the 'problem area' is defined. In this step, various scientific approaches derived from social science as well as behavioral science are applied to unearth the right problems. Second, the 'goal area' is defined based on the problems found in the previous step. The 'goal area' is usually described as user "needs". In this step, similar to the previous step, various scientific methods from the social and behavioral sciences can be applied to define the 'goal area'. Defining the 'goal area' is the process of determinizing the 'solution area' and converting an indeterminate 'solution area' to a quasi-determinate 'goal area'. Third, solutions which satisfy the defined goal are created or invented. In this step, based on the 'problem area' and 'goal area' defined in the previous steps, an ideal solution that can satisfy the goal as well as the problem is created. This step is a fully indeterminate state, hence there are unlimited possible solutions that can satisfy the goal. The fourth step is the 'evaluation'. The final solution is evaluated in two ways. The first evaluation is an evaluation of the 'solution' - the 'product' which is produced through the design process. The second evaluation is an evaluation of the determinization level of the 'goal area'.

The 'Problem-Solving Model of Design' suggested in this study is composed of several parts: a 'problem area', a 'goal area', a 'solution area', a 'solution evaluation' and a 'goal evaluation'. The functions of each part are as follows:

A. Problem Area: The property of this area in design research is quasi-determinate. This area has a certain boundary which confines the area and makes it determinate within the boundary. However, within the determinization boundary it is indeterminate, which means during the problem-solving process, through an evaluation of the solution, other problems can appear, and these new problems can be interrelated or can conflict with the initial problem. As a result of the quasi-determinate property of the 'problem area', the scientific approach of 'discovery' can be applied in this area. Finding the right problems is as important as finding good solutions (Einstein & Infeld, 1938; Jonas, 1993; Nadler, Smith & Frey, 1989). It is fairly important to scrupulously and systematically find the very factors which users or societies consider to be problems.

B. Goal Area: The property of this area is quasi-determinate, which is determinate as a whole but indeterminate within the determinization boundary. The 'Goal area' is indeterminate in the sense that the scope of the 'goal area' can be varied according to the determinization level from a more determinized and decomposed state to a more abstract state. Conversely, the 'goal area' is determinate in that the fundamental goal as well as each goal at each level of deteminization is determinate. Owing to the quasi-determinate property of the goal area, only if the determinzation level is defined, the scientific approach of 'discovery' can be applied in this area. Setting a proper goal is important, as a defined goal provides a guideline for creating solutions.

C. Solution Area: The property of this area in design research is indeterminate, and therefore the non-scientific approach of 'invention or creation' can be applied. Inventing solutions is based on the 'problem area' and 'goal area'; based on these two areas, various creative activities can occur. Various methods for creative thinking, such as 'brainstorming', 'stripping down to fundamentals', 'playing with toys', or others (Petre, 2004) can be applied. The production of unlimited numbers of solutions are possible for each problem and goal; accordingly, an evaluation that finds more appropriate solutions to satisfy the goal as well as to resolve the problem more successfully is necessary.

As the 'process' as well as the 'solution area' in design research are indeterminate, evaluations to find better processes and solutions are needed. The evaluation element is composed of an evaluation of the 'solution', which is connected to the 'product' and that of the 'goal', which is in turn related to the 'process'.

D. Solution Evaluation: The criteria for this evaluation are not 'right or wrong' but 'good or bad' (Newell & Simon, 1972; Owen, 2005). 'Good or bad' is determined based on the following: how successfully the goal is satisfied, and how effectively the given problems are resolved. When the solution is 'good', the solution becomes the final solution (Jonas, 1993). However, if the solution is evaluated as 'bad,' the problems of the solution should be discovered through evaluation, and an iterative problem-solving process should be executed as shown in Fig. 4. The newly produced problem (problem B in Fig. 4) is the problem for the solution (Solution A in Fig. 4), while at the same time it is a subsidiary of the initial problem (Problem A in Fig. 4) (Buchanan, 1992; Newell & Simon, 1972; Rittel & Webber, 1973). Both problems should be considered while redefining a 'new goal'(Goal B in Fig. 4) and creating a 'new solution'(Solution B in Fig. 4). While evaluating the second solution, 'Solution B', how successfully 'Solution B' satisfies 'Goal B' and how well 'Solution B' resolves both 'Problem A' and 'Problem B' should be considered. An iterative process should be continued until satisfying solutions are found.

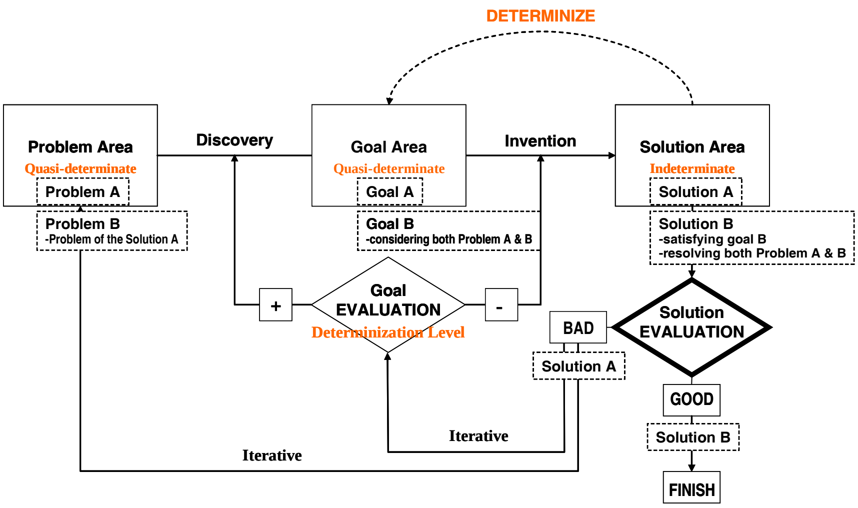

Figure 4. Solution Evaluation and Iterative Process of Problem-solving

E. Goal Evaluation: 'Goal evaluation' is an evaluation of the determinization level of the 'goal area' as shown in Fig. 5. The determinization level determines the composition of the problem-solving process by controlling the distribution ratio of the scientific approach of 'discovery' and the non-scientific approach of 'invention'.

The criteria for 'goal evaluation' depends on how successfully satisfying solutions can be produced and how efficient the problem-solving process is at that determinization level. If the determinization level is evaluated as 'good', it is deemed to be at the proper level to aid in problem-solving activity toward a given problem. Conversely, if the determinization level is evaluated as 'bad', iterative processes that seek to find the proper determinization level are needed. The evaluation result of 'bad' originates in two conditions. The first of these is caused by the condition of insufficient creativity. In this case, a decrease in the determinization level is needed to increase the portion of 'invention' and decrease the portion of 'discovery'. The second is due to the condition of an ambiguous and inefficient problem-solving process. In this case, an increase in the determinization level is necessary to increase the rate of 'discovery' and decrease the rate of 'invention'. Through iterative processes, the optimum determinization level which effectively aids the design activity should be found.

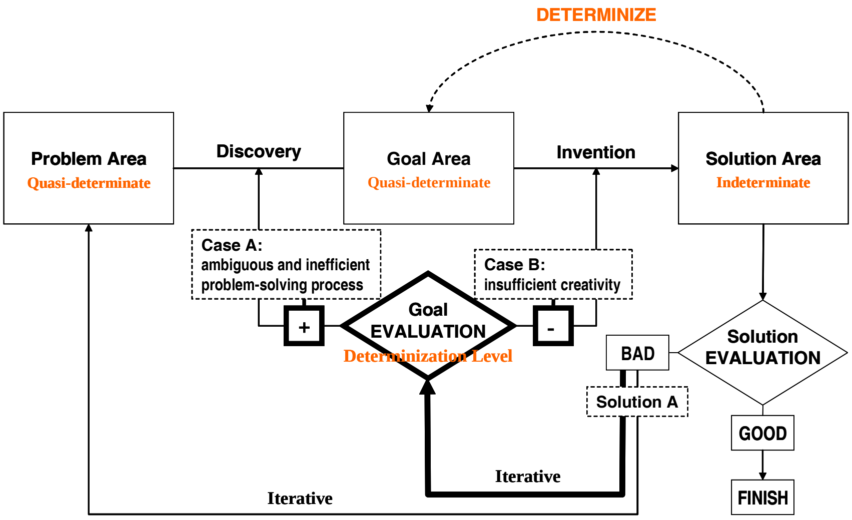

Figure 5. Goal Evaluation and Iterative Process of Problem-solving

3.3 Determinization Level

A. Determinization Level of Goal Area

The determinization level of the 'goal area' determines the proportion between 'discovery' and 'invention' in a 'problem-solving process'. It affects the "level of creativity" of the 'solution' and the "level of efficiency" of the 'process'. The 'level of creativity' is one of various values that evaluates the 'solution' and is closely related to 'invention' in the 'problem-solving process'. The 'level of efficiency' is one of various values that evaluates the 'process', and is closely connected to 'discovery' in the 'problem-solving process'.

B. Control of Determinization Level

When the determinization level is heightened as shown in the addition control in Fig. 5, the portion of 'discovery' increases, and that of 'invention' decreases. With a high determinization level, the 'level of efficiency' increases due to the more systematic and logical approach by 'discovery', while the 'level creativity' of the 'solution' decreases.

Alternatively, when the deteminization level is lowered as shown in the subtraction control in Fig. 5, the portion of 'invention' increases, and that of 'discovery' decreases. With a low determinization level, the 'level of creativity' of the 'solution' increases, while the 'level of efficiency' of the 'process' decreases (Dorst & Dijkhuis, 1995).

In addition, assuming that the same problem is given, the determinization level also determines the size of the 'goal area' as well as that of the 'solution area'. When the determinization level increases, the size of the 'goal area' becomes smaller, which means that the level of decomposition of the goal becomes higher, hence the size of the 'solution area' also becomes smaller, which indicates that the number of possible solutions decreases (Shown in Fig. 6 (a)).

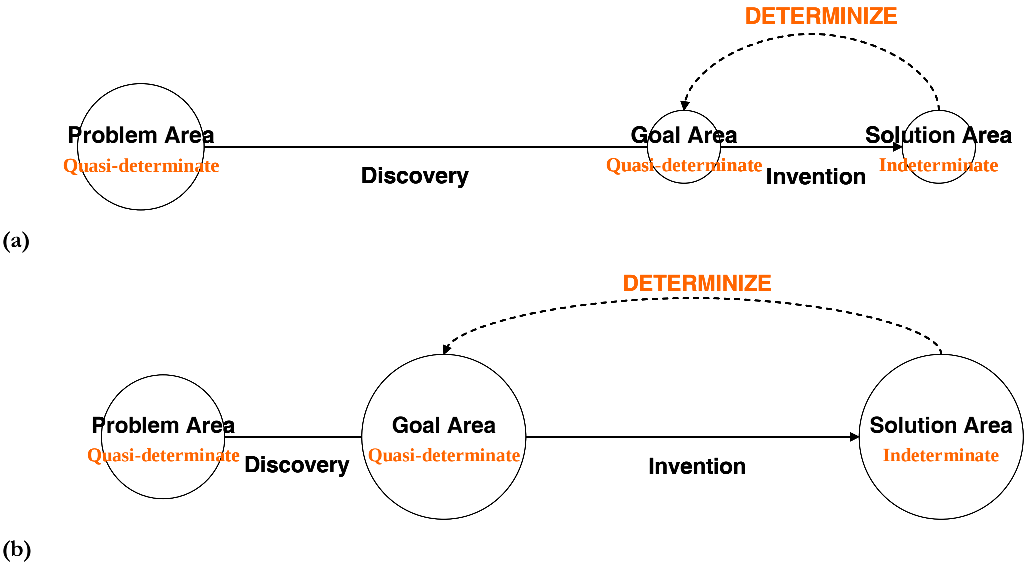

Figure 6. Relationship between Determinization Level and the Size of the Goal Area and the Solution Area

Conversely, when the determinization level decreases, the size of the 'goal area' becomes larger, which denotes that the level of decomposition of the goal also becomes lower, hence the size of the 'solution area' also becomes larger, indicating that the number of possible solutions also increases (Shown in Fig. 6 (b)).

In 'Designing Variations', Oxman (1986) introduced the 'limits of variation' and described how the degree of diversity in conditions affects the variability of the solutions. The determinization level in the present study seems similar to the degree of variation in Oxman's paper in the sense that both are controllable and determine the size of the solution area. However, the determinization level and the degree of variation are distinguished in that the determinization level controls the process of the design as well as the solutions while the degree of variation only determines the solution area (Oxman, 1986). Moreover, while the determinization level determines the boundary of the goal area, the degree of variation determines the possible number of components to be used while designing solutions. Nevertheless, the level of creativity in Oxman's 'componentizing' strategy is limited for the reason that possible solutions are based on the existing components.

The determinization level determines not only the level of 'discovery' and 'invention' but also the size of the 'goal area' and the 'solution area'. In the following section, two cases at an extreme determinization level in two sides, the 'full discovery' and the 'full invention' are described.

<u>The 'Full Discovery'</u>: When the portion of 'discovery' becomes 100 out of 100 and that of 'invention' is zero as shown in Fig.7, the 'level of efficiency' of the process increases, but the 'level of creativity' disappears. In this case, the goal gets broken down to the solution level; consequently the size of the 'goal area' is equal to that of the 'solution area'. The fact that the 'goal area' and the 'solution area' overlap indicates that the final decomposed goal is identical to the solution. This state implies that there is no role for designers who have the ability of creation. That is to say, if anyone follows the procedure as it is, everyone reaches an identical solution.

Many efforts concerning 1920's design methodologies which focused mainly on scientising a solution are good examples which explain a 'full discovery' case (discovery=100, invention=0). However, as can be seen from history, with 'full discovery', creative design cannot be produced. This is connected with the concept of the differences between 'decision attitude' vs. 'design attitude', as Boland Jr. and Collopy (2004) introduced in 'Managing as Designing'. 'Decision attitude' which corresponds to 'full discovery', can provide the best choice from the existing alternatives, but it cannot create new alternatives which better correspond to new problems.

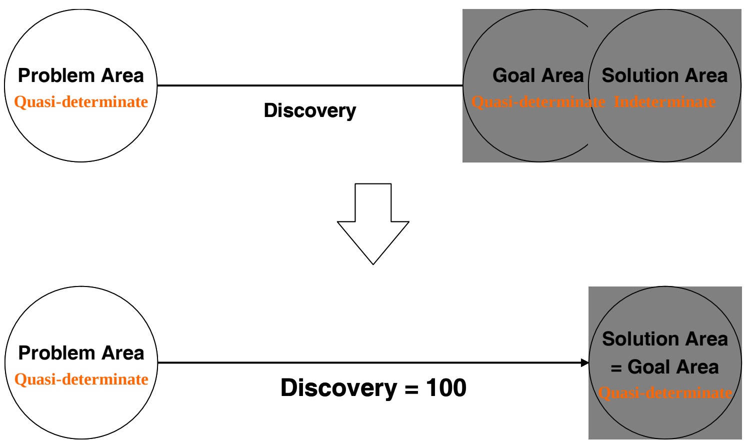

Figure 7. Full Discovery

Conversely, 'design attitude' creates new alternatives (Holt, Radcliffe & Schoorl, 1985; Myatt, 1962), and therefore can provide ideal solutions for newly confronted problems (Boland Jr. & Collopy, 2004). The 'Analogical Reasoning (AR)' approach (Findler, 1981) is another good example which explains the limitations of the discovery-focused approach for the design activity. The 'model of AR' is a mapping system either directly between problems and solutions or indirectly between problems whose solutions are similar. Although this system can produce various design solutions, the solutions are not new solutions but are at best re-compositions or re-arrangements of existing solutions.

There are several reasons why 'full discovery' is unproductive. First, there is the possibility of discarding or ignoring important sources or sub-goals during the process of determinization; second, there can be unsuccessful decompositions or combinations during the process of determinization; third, a synergy effect based on 'problem space' and 'goal space' is needed in the process of design, due to the "wicked" characteristic of design problems (Rittel & Webber, 1973). For this reasons, a problem-solving tree broken down to one solution through one path (Newell & Simon, 1972) is not applicable for design problems. The fourth reason has to do with the fact that new alternatives cannot be created. In the condition where discovery = 100 and invention = 0, only a 'decision attitude' is possible while 'design attitudes' do not exist. Consequently, considering the restraints of 'full discovery', evaluations and research that find a more adequate determinization level, which provides an effective stepping-stone to create new and creative solutions, are necessary.

The 'Full Invention': Conversely, when the portion of discovery is zero and that of invention is 100 as shown Fig. 8, the 'level of efficiency' decreases greatly but the 'level of creativity' increases. In this scenario, the 'goal area' is eliminated, as the determinization level is zero, and designers create a solution directly from the problem area without the use of a goal area. This situation is usually referred to creation by inspiration or intuitive processes (Cross, 2001; Dorst & Dijkhuis, 1995; Glynn, 1985). Descriptions of art and design activities as intuitive processes through certain inspirations are good examples which illustrate design research in the condition of 'full invention'. Although 'full invention' can provide more creative solutions as well as processes, it does not include any portion of a discovery area. This indicates that design cannot become a discipline which can be universally, rationally, or scientifically explained (Cross, Naughton & Walker, 1981; Dorst & Dijkhuis, 1995). Nor can it be taught, further implying that only a small percentage of people who have intuitive talent can be designers (Dorst & Dijkhuis, 1995).

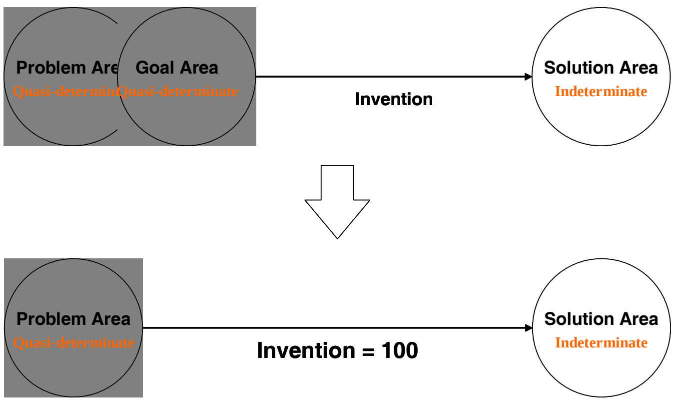

Figure 8. Full Invention

C. Dilemma of the Determinization Level

The essential roles in design research are to find a proper determinization level which induces an effective problem-solving process as well as one that produces more creative and better solutions. With a proper determinization level, the activity of determinizing the 'goal area' aids the 'problem-solving process' by making the process more systematic and efficient. However, if the determinization level exceeds a proper level, although it may increase the level of efficiency of the 'problem-solving process', it will likely decrease the level of the creativity of the 'solution'. Conversely, if the determinization level is below a proper level, although the level of creativity may increase, the level of efficiency will likely decrease.

4. Testifying of Problem-Solving Model of Design

In this section, illustrative examples explaining functioning of the proposed model with respect to 'solution evaluation' and 'goal evaluation' are described. In the first part of this section, 'God's creation' is described to illustrate that the proposed model is applicable to design processes at any level of creativity and to introduce the process of the 'solution evaluation'. The second part, which gives you an idea about the concept of 'goal evaluation', illustrates three different examples at different determinization levels in order to show that the proposed model fits different types of the design process with a controllable determiniation level.

4.1 God's Creation in the Gene of the Bible

In order to show that design activities at any level of creativity have quasi-determinate factors, God's creation, the most creative process which produces the most creative products, is used as an example. If God's creation can be explained based on the problem-solving model of design, the model here will be a model which is applicable to any other creative design activity. The objectives of this illustrative example are to determine whether God's creation involves quasi-determinate areas with a certain determinization level, and to explain the functioning of the problem-solving model of design.

The problem-solving activity regarding the problem of "Adam's being alone" can be analyzed as follows: According to (Gene 2:18), it is written that "It is not good for the man to be alone. I will make a companion who will help him." In this verse, 'It is not good for the man to be alone' is the 'problem', and 'to make a companion who will help him' is the 'goal'. In this verse, the content of "help(ing)" is 'tending and caring for the Garden of Eden' (Gene 2:15). In order to satisfy this goal, the first solution was to introduce 'livestock, birds, wild animals' to Adam as companions (Gene 2:19-20). However, as described in (Gene 2:20) "But still there was no companion suitable for him", the result of the evaluation of the first solution was that it was not good enough. Thus, an iterative process was executed in order to find a better solution. The problem and the goal of the first iterative process are identical to those of the initial problem-solving process, which were that it was "not good for the man to be alone", and to "make a companion who will help him" respectively.

Through the iterative process, "woman" was created as the second solution (Gene 2:22). As written in (Gene 2:23-24) ""At last!" Adam exclaimed. "She is part of my own flesh and bone! She will be called 'woman,' because she was taken out of a man"", the evaluation toward the second solution was satisfactory, and the problem-solving process is completed. As shown in the verses (Gene 2:20) and (Gene 2:23-24), the solutions are evaluated by the customer of the product, 'Adam', and according to the result of the evaluation, subsequent iterative processes proceeded. The problem-solving activity of this case study can be illustrated based on the problem-solving model of design as shown in Fig.9.

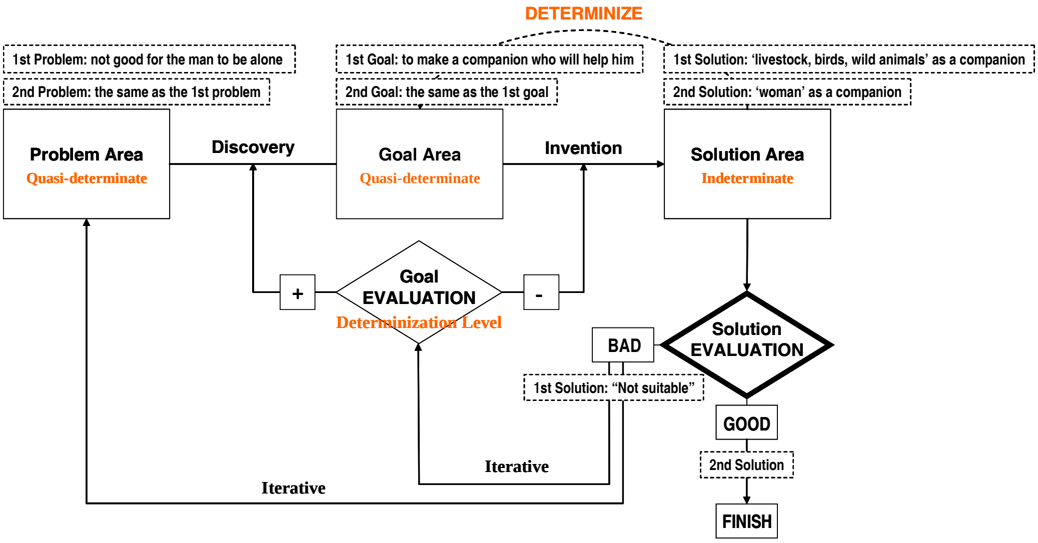

Figure 9. Problem-solving activity regarding the problem of "Adam's being alone"

Although this example does not demonstrate the 'goal evaluation process', it satisfies the hypothesis that all design activities involve a quasi-determinate area with a certain determinization level. This hypothesis is supported by the fact that the goal and solution are distinct entities in that they are at different levels in the hierarchy. The goal, 'Companion' is situated in the upper level of the hierarchy and is a larger set ('Companion' ⊃ 'livestock, birds, wild animals' and 'woman') than the solutions of 'livestock, birds, wild animals' and 'woman'. That is, in God's creation, the determinization level of the goal was set within the limits of 'companion', and within the scope of 'companion', 'livestock, birds, wild animals' and 'woman' were created as solutions.

The illustrative example of 'God's Creation in the Bible' shows that even in the most creative design process, the 'problem area' and the 'goal area' can be partly determinized, and the 'solution' is produced through a 'solution evaluation' and iterative processes.

4.2 Examples of Various Determinization Levels

The second set of examples is related to goal evaluation. The objective of the examples is to discover how different types of design activities are mapped on different determinization levels in the proposed problem-solving model, and to resolve the acceptability of the model in covering various types of design activities. Three examples– the 'axiomatic design' which is a theory of the design process, the 'precise and imprecise problem formulations' which is a way of design process, and the 'God's creation in the Bible' which is an illustrative example - are analyzed based on the problem-solving model of design proposed in this study.

Case1: The axiomatic design (Suh, 2001), which decomposes all functional requirements and matches them to independent design parameters, is a case of a high determinization level in the problem-solving model of design.

Case2: Fricke's(1999) study on the proper approaches for precise and imprecise problem formulations concludes that an imprecise problem formulation requires more time than a precise formulation for goal analysis. This implies that the problem-solving model at a high determinization level is appropriate for an imprecise problem formulation, and one at a low determinization level is effective for a precise problem formulation. The 'precise and imprecise problem formulations' case illustrates the flexibility in the control of the determinization level in the problem-solving model.

The mapping of the three cases on the problem-solving model is displayed in Fig. 10.

Case3: God's creation (Gene 2:15-24), which begins with no existing solutions and represents the most inventive design activity, is a case of a low determinization level in the problem-solving model of design.

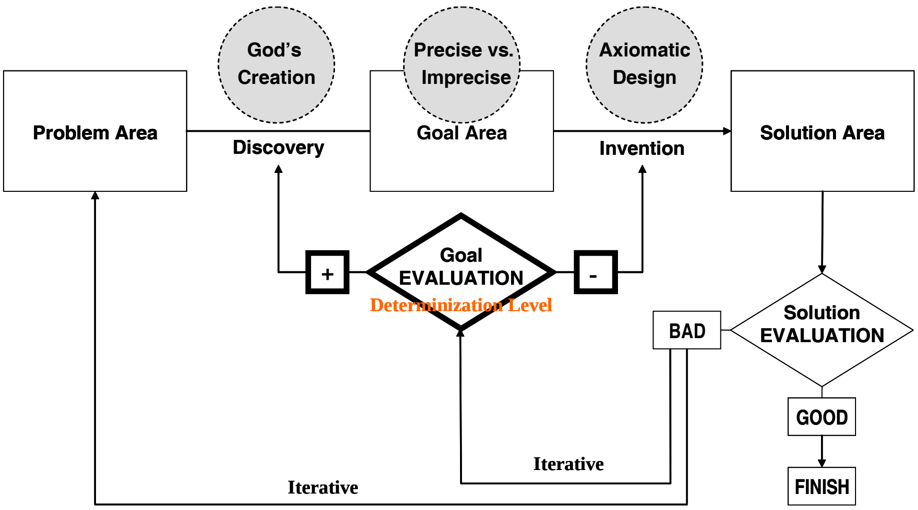

Figure 10. Mapping Examples of Design Activities on Problem-Solving Model of Design

5. Conclusion

This study proposed a problem-solving model of design which is divided into two parts – a quasi-determinate part which can be approached with "discovery" and an indeterminate part which can be dealt with "invention". The proposed model is goal-oriented and is based on the triad relationship among a problem, solution and goal. Determinization level determines the portion between discovery and invention, and it is controllable according to various conditions. This indicates that the problem-solving model of design with a controllable determinization level is not only suitable for "wicked problems" of design which includes indefinite conditions, but also applicable to all types of design activities.

Also, examples were illustrated to explain functioning of the model. 'God's creation in the Bible' was described to depict the process of solution evaluation, and three examples at different determinization levels were described to explain the process of goal evaluation. The fact that 'God's creation in the Bible' was explained based on the problem-solving model of design indicates that problem-solving model is applicable to design activities at any level of creativity. In the three examples of different determinization levels, different types of problems in different conditions were matched with different determinization levels. This showed that the control of determinization level correlates the solution structure to process.

Appropriate determinization levels according to various conditions, such as different designers(experts vs. novices), environments(new product development department vs. manufacturing department), and types of problems(precise vs. imprecise problem formulations) should be further explored.

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