



HAL
open science

Concept Design of Appropriate Technology Based on Circular Economy for Sustainable Development Inferred from Korea Traditional Heating System

Sehoon Cho

► **To cite this version:**

Sehoon Cho. Concept Design of Appropriate Technology Based on Circular Economy for Sustainable Development Inferred from Korea Traditional Heating System. TRIZ Future conference, Sep 2021, Bolzano, Italy. pp.74-88, 10.1007/978-3-030-86614-3_6 . hal-04067810

HAL Id: hal-04067810

<https://inria.hal.science/hal-04067810v1>

Submitted on 13 Apr 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Concept Design of Appropriate Technology Based on Circular Economy for Sustainable Development Inferred from Korea Traditional Heating System

Sehoon CHO¹[82-10-2712-7560]

¹ Mechanical Design Engineering, Korea Polytechnic University,
30, Beolmal-ro, Bundang-gu, Seongnam-si, Gyeonggi-do, South Korea
sh68.cho@gmail.com

Abstract. Research continues on the design of products that do not create serious problems for sustainable development and natural ecosystems. What should be considered in the design to minimize harmful consequences in the product's entire lifespan, such as the manufacturing process, during use, and after the end of its life?

Heating and cooking methods, which have been used in traditional Korean houses for more than 1,000 years, are observed in terms of TRIZ's resource analysis, systematic thinking, and functional analysis, and the characteristics found in them are summarized. It extracts the characteristics of the concept of a circular economy by analyzing its technological system properties, interactions of constructs, invention principles, and resource properties over time. Ondol systems are highly recyclable, with most of the components that make up the system from a circular environment perspective being reused as a cycle of resources.

Thus, these features demonstrate the importance of predicting and analyzing the interactions of each configuration over time as an extension of system thinking in the early stages of planning a technical system, in the resource analysis and utilization of the components that make up the system in conceptual design.

Keywords: Concept Design, TRIZ, Resource, Circular Economy, Appropriate Technology, Sustainable, Heating System, Ideality, Multi-Screen Thinking

1 Introduction

It is becoming clear that climate and environmental pollution issues, including global warming, are no longer a situation that a specific country or environmental group must deal with and try to solve. And destructive development of the natural environment, waste of resources, and product development that could cause pollution and waste should be stopped. However, how to make the necessary things in life and not make those problems in the process of using nature is a task that all of us must solve.

To solve the problems, research has been underway for a long time on Circular Economy, an eco-friendly economic model that focuses on "recycling" and "reuse." The circular economy collectively refers to an economic system to reduce waste and make the

most of resources [1]. In other words, activities focusing on a variety of resource cycles have been proposed, not on a linear approach that ends after using something man-made, but on recycling it for reuse [2].



Fig. 1. Life threats from plastic pollution [4].

Every year, 25.8 million tons of plastic waste are poured out of Europe alone, of which only 30% is recycled, 31% is landfilled, and the remaining 39% is incinerated, according to the EU Commission [3]. It is known that 10 kinds of plastic products that are used daily, such as straws, drinking water rods, occupy 70% of the total marine waste along with the fishing tools thrown away [4]. These wastes threaten the healthy survival of animals, such as Fig.1.

In 1987, the United Nations' World Commission on Environment and Development defined sustainable development. Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This sustainability is an important course of action for innovation and is progressing towards sustainability-oriented innovation by integrating economic, social, and environmental responsibility into innovation management [5, 16]. In the indexed in Scopus, more than 12,000 studies on eco-friendly design were conducted, and 25% of them suggested various design guides and methods [6]. Korea's interest and research on such sustainable development can be found from 1992 [7]. 17,622 articles were searched (2021.4, scienceon.kisti.re.kr) in the DB of Korean papers containing "sustainable". In these studies, 59 summarized guidelines were presented [6, 21], summarizing various methodologies, guidelines, etc., and another method was presented [20].

However, despite this research and efforts, we are still facing many problems in the manufacturing, use, and disposal of a number of products, and we are making another effort to solve them. Laws and regulations are being made internationally, and various guidelines and methods are being proposed, but their effects are not easily seen. Therefore, more practicable product design criteria or methods are needed. It would be helpful if the key checks available earlier in the conceptual design were properly presented.

2 Situation and Problems of Existing Appropriate Technology

The various studies and efforts for such sustainable development can be summarized as "the skills needed to improve the quality of human life", and this is substantially the same as the definition of appropriate technology in a broad sense [23]. Specific definitions of appropriate technology exist in a variety of ways. One of them is a technology

that does not require high investment, uses less energy, can be easily learned and used by anyone, uses raw materials locally, and allows small people to gather to produce products [23]," which contains a lot of economic feasibility. In 2010 Paul Polak argued that in *the death of Appropriate Technology* many attempts at appropriate techniques have failed [8]. The ruthless pursuit of affordability is an essential component of this design revolution, which in many ways stands on the shoulders of the appropriate technology movement. It means that economics is the most important requirement in the initial and operation of the appropriate technology result itself. The term "economically" means the whole of the initial purchase, installation, use, and maintenance of technology. The representative failure cases are *Glowstar Solar Lantern* and *Manual Sunflower Oil Press*, and these are expensive for locals in initial introduction. In addition, *Play Pump*, *Life Straw*, and *Q-Drum* have low economic efficiency in terms of initial price, maintenance, and practical efficiency, and some cases may be obsolete or discarded [9, 23].

In general, the development and provision of appropriate technologies have achieved good intentions and objectives. However, such results are often discarded or unanticipated by changes over time and place. It may be the result of changes in the properties of the initially introduced resources over time or changes in interactions. There are also additional problems with the persistence and securing of resources used for problem-solving. In addition, most of the cases are not reused or recycled after the end of their life and are likely to become waste locally. The problem has been solved in the short term, but if time and space are expanded, harmful consequences can occur. This means that there is a possibility of hidden harmful effects in the current solution. Often, the properties of the parts or materials that make up the product change over time, and new problems arise in the interaction with the surrounding environment. These may come from the failure to anticipate potential harmful effects in the problem-solving procedure or to consider the possibility in the initial design. From the perspective of TRIZ, this is a macroscopic contradiction. That is, a beneficial effect appears in the beginning, but a harmful effect appears gradually, and eventually the two effects coexist. Such a situation can be seen as not solving the problem from a macroscopic point of view. It is not an appropriate solution from a long-term perspective if new problems arise in the customer or environment using the appropriate technology, including in the process of use or after the end of life, or if the economics are low or not in the treatment process. In the end, if potential problems, including economic issues, emerge according to changes in time or place, it can be said that it is still a problem situation that has not been solved from the perspective of sustainable development or circular economy.

3 Conceptual Design Approach for Sustainable Development

3.1 TRIZ tools for appropriate technology including Circular Economy

In general, the areas where appropriate technology is applied are often developing countries, so there may be misunderstandings about the characteristics of appropriate technology. For example, it can be considered technically low-level or recycling technology, or minimal technology for survival. However, the concept of appropriate technology is a type of engineer seeking optimization within the given conditions rather

than seeking changes in the entire system to address the problem situation [24]. This concept is similar to TRIZ's ideality. In other words, it uses minimal components, minimal energy, or free resources in the process of obtaining the desired functionality or performance.

The development of appropriate technology is generally the same as the process of finding a solution in each problem situation. From the perspective of sustainable development and circular economy, it is necessary to analyze changes in interaction with time and surrounding environment to develop appropriate technologies to solve potential problems. TRIZ's Multi-Screen Thinking/Method (MST) is a tool used to analyze problem situations and resources for problem solving through the analysis of the interaction relationship between the time of the technology system and the internal and external environment. From this MST perspective, the macro-objective of sustainable development and circular economy is to ensure that products and components do not produce harmful effects or consequences in their interactions with the surrounding environment before and during use. For example, in an internal combustion engine vehicle running on a general road, problems such as dust, soot and noise, tire wear, road wear, collisions with vehicles and people exist while driving. After use, it still has various problems such as waste tires and recycling due to scrapped cars. It is the same means of transportation, but in the case of drone taxis, which are currently being commercialized, there is no soot due to motor drive, the dust problem is minimal, and there are no roads or tires to be worn. This could be an advanced system from a more sustainable development perspective. Therefore, the appropriate technology should have a macroscopic ideal that achieves economical and sustainable development without harmful interactions during the product lifecycle in the user and the environment of use. The lifecycle of a product or system can be summarized in the form of Table 1 by making a table using MST in terms of the level and time of the interaction area.

Table 1. Product Lifecycle and Potential Problems Using MST.

Time Level	Past (Before Use)	Present (In Use)	Future (After Use)
Super-System (Macroscopic Ideality)	Utilization and disposal of by-products	Environmental pollution (Noise, air, water, soil)	Environmental pollution (Noise, air, water, soil)
System	Manufacturing process issues Postprocess Handling Problem	Problem with by-products in use Problems during operation (waste, failure)	End-of-use, end-of-life processing issues Recycling of products
Sub-System	Material procurement issues Pre-processing/preparation issues for materials	Ease of repair and replacement of components	Ease of decomposition Recycling, reuse of parts and materials Disposal costs and hazardous materials risks

To realize such ideality, resource analysis through MST analysis and initial conceptual design should be made to have the characteristics of the circular economy. It is necessary to consider the occurrence of new problems due to OT in OT (Operation

Time) and OZ (Operation Zone). As the degree of disorder increases for most existing substances, the level of interactions or components that make up the system deteriorates rather than initially. Therefore, the range of problem situations to be solved in product development that includes appropriate technology must be extended to include potential problems in the present and in the future. The goal and scope for the solution should be designed by expanding it in time and space. In other words, it should not be limited to the goal of the solution in terms of the current temporal and environmental aspects of the customer or the local area requiring problem-solving. The solution is to avoid creating new problems in situations where a certain amount of time has elapsed and lifespan is over, or when the initial problem situation no longer occurs and is no longer needed. Items made with most solutions end of life, become obsolete, break down, break during use, or require repairs. In many cases, new problems arise during the disposal process. In other words, the cycle of circulation was broken in the entire cycle of the product. Therefore, the concept of the circular economy should be included in technology development and product development including appropriate technology.

In general, the ideality of TRIZ can be understood to be for solving a given problem situation at a specific point in time. Therefore, the level of the ideality of a given resource is partially adjusted and the IFR for the final problem situation is determined by the decision-making process. However, since this is pursuing the IFR for a specific time and place from the beginning, it has not reached the ideality in terms of the circular economy. Consequently, achieving true ideality should be technical problem-solving considering life cycles that include the concept of the circular economy rather than merely implementing the required functions and performance. This can be called extended ideality with a concept of time.

3.2 Conceptual design including sustainable development in product and service development

DFx (Design for x) is a design strategy that considers the entire life cycle of a product from product development, manufacturing, use, and disposal when planning a product in a manufacturing-oriented company [10, 11]. The parameters corresponding to X in DFx include Product, Assembly, Quality, Cost, Manufacturability, Customer Satisfaction, Environment, Recycling, Reuse, Safety, Reliability, and Procurement. These are planning products in the dimension of 'Total Cost' and 'Product Lifecycle Management' in the development process to secure basic functions and performance in conceptual design. Given that the company's social responsibility is strengthened and the final responsibility for the manufactured and sold products is given, the planning and design of products based on DFx is a form of approach for sustainable development and a circular economy. Most of the global companies are promoting and researching every year that they are making efforts for eco-friendly, circular economy, and sustainable development [17, 18, 21]. These DFx parameters are the attributes that the product must have at each time in the product's life cycle. In addition, they are also desirable requirements that the parts constituting the product or the higher environment around the product must be provided at each time. Therefore, these parameters can be organized as shown in Table 2 through TRIZ's MST (or 9 Windows).

Table 2. Design for x in Multi-Screen Thinking.

Level \ Time	Past	Present	Future
Super-System	Recycling Cost	Customer Satisfaction, Environment Safety, Cost	Environment Safety Cost
System	Product Assembly Manufacturability	Quality Reliability Cost	Recycling Reuse
Sub-System	Procurement Reuse	Procurement Recycling	Recycling

Interaction occurs with the Super-System and Sub-System before, during, and after the use of the system (product or developed technology). Such interaction exposes hidden resources and generates derivative resources, such as deepening of resource analysis. In some cases, such hidden or derived resources may have harmful or beneficial effects on the Super-System and Sub-System. After all, product, or technology development in consideration of sustainable development and circular economy can be said to be a strategic approach similar to DfX-based conceptual design. In the initial concept design stage, a design that minimizes subsequent problems should be made by sufficiently considering the entire life cycle of the product. This design strategy should be applied in more depth, especially in the development of appropriate technologies for developing countries. Early low-cost solutions can be used temporarily. However, the unexpected occurrence of Cost in the forerunner of a product is less economical and can sometimes be fatal to actual use. Consequently, the conceptual design of appropriate technology for sustainable development should be reflected in the initial design by analyzing the harmful effects and the likelihood of additional costs of interaction with various elements of the environment in which the product is used.

4 Case Study

4.1 Resources and appropriate technology for heating and cooking

The weather in Korea has four distinct seasons, and there was a heating problem due to cold in late autumn, winter and early spring. In addition to heating in preparation for such cold, cooking problems consist of 60% to 70% of the country, but it was not easy to secure wood with firewood. It was a situation where heating and cooking problems had to be solved with little firewood. These heating and cooking problems, along with housing problems in most poor countries and regions, are the first problems that must be solved for the basic life of human beings and are subject to appropriate technology. Korea's 10 degrees Celsius or less runs from September of the year to May of the following year. Usually, in January and February, it often falls below -10 °C. Therefore, in Korea, heating is required for about 8 months of the year [12]. See climate table of Korea. In addition, since the Korean region is characterized by high temperature and high humidity in summer and low temperature and low humidity in winter, the necessity of removing moisture along with heating is also high. In this situation, the heating

and cooking problem can be summarized into four by summarizing what is required for the solution. These requirements also exist in the late 17th century records [26].

- Limited amount of firewood and efficient use
- Maintain the proper temperature during bedtime
- Use minimal firewood for cooking
- Ease of repair or maintenance

After all, the main requirements can be summarized as the problem of efficient heat energy management and utilization by insufficient energy source (firewood). It uses a minimum of firewood and requires heating for at least bedtime (6-8 hours), and it is not hot, but it is necessary to continuously supply heat energy to have a comfortable rest. Consuming a large amount of firewood in a short period of time makes it inappropriate to sleep at high temperatures. Therefore, the combustion of firewood must be controlled to have a constant fire power while burning as slow as possible. In general, firewood is characterized by relatively long burning according to its size, but it is sometimes difficult to secure such firewood. The bark, twigs, straw, and branches of most shrubs and agricultural products burn well, but the firepower is temporary. Regardless of what is being burned, the combustion process must be controlled as needed. This problem of supply and demand of firewood further increases the need to control the combustion process of firewood or other wood used for heating or cooking. In addition, in situations where firewood must be used for separate cooking, the minimum amount of firewood should be used. And if the solution created is often broken, has a short life, or is difficult to repair, it becomes a new problem.

In the form of housing in Korea, after the Bronze Age, a unique heating method with a stove and flue began to appear in the kitchen provided inside the house. It is estimated that Korea's unique heating type has been found in all regions of Korea at a site estimated to be a relic of about 300~100 B.C. It is estimated that Korea's unique heating type has been used for more than 2,000 years. This unique type of heating in Korea is called ondol. Ondol is a form of domestic heating having a flue or flues running under-floor from a fire or furnace [13]. Fig. 2 is a typical Korean rural wooden thatched house built about 200 years ago, and the chimney is made of stone and soil [14].



Fig. 2. Typical Traditional Korean Rural House [14].

Fig. 3 is a picture of a part of the kitchen separated from the bedroom space, which corresponds to the entrance for burning firewood in such an ondol. (a) is the entrance to the combustion chamber exclusively for heating, and (b) is a typical view of the kitchen corresponding to the combustion chamber for both cooking. Smoke from the combustion of firewood by heating or cooking is discharged through chimneys arranged on the side, front, and rear of the house in Fig. 2.



Fig. 3. Ondol Combustion Room Entrance (Kitchen) [14].

4.2 Basic structure and general characteristics of Ondol

Fig. 4 shows a part of the general structure of Ondol and is a schematic diagram of the rough cross-sectional structure of a house where I actually lived in my hometown (built about early 1900). The cross-sectional structure of the ondol has slightly different parts depending on the size of the room or the location of the chimney, but most have a similar basic shape.

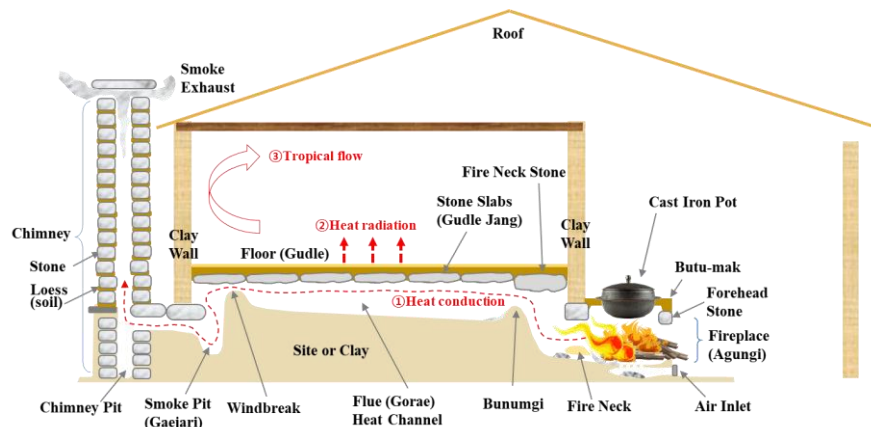


Fig. 4. Cross Section-Vertical Structure of Ondol Room.

Fig. 4 and Fig. 5 roughly shows the vertical and horizontal sections of the front of the house. The entrance to the combustion chamber is called 'Agungi', and a door made of mainly iron that can open and close is installed. When firewood is fed through the Agungi and burned in the combustion chamber, a pot for cooking is placed on the flame. The flame passes through the 'Fire Neck' in the combustion chamber, passes through the space where sparks and dust that can move along with the flame sink, and passes through the primary gate called 'Bunumgi'. As it passes, most of the flames change to a heated state, and move to the 'Gorae (Heat Channel)' which is divided into several branches. Gorae has a shape that decreases in height toward the rear chimney as shown in Fig. 4. This heat transfers heat to the 'Fire Neck Stone' and 'Gudlejang (Stone Slabs)', which are placed stones after the combustion chamber. This heat conduction weakens as it goes to the rear of the room floor, and the heat decreases in temperature,

and passes through the 'Windbreak' before being discharged to the chimney. Arranged at the end of each 'Heat Channel', this is the narrowest gate, and the heat stays within the channel as much as possible. In addition, this gate prevents the inflow of cold air that may come in through reverse flow of smoke discharged from the outside or from the chimney. In particular, the 'Smoke Pit' prevents the inflow of cold air from the outside, so that the heat with excess heat energy that has passed through the Windbreak finally stays and is pushed back to the chimney and discharged from the chimney. The 'Chimney Pit' installed at the bottom of the chimney is usually installed at the lowest position in the Ondol structure, and functions to gather there without moisture, groundwater, or rainwater flowing into the bottom of the Ondol.

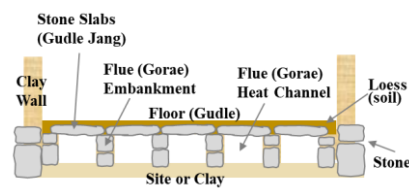


Fig. 5. Cross Section-Horizontal Structure of Ondol Room.

In the lower part of the combustion chamber, there is a narrow and long passage for supplying additional air required in the combustion process of firewood or for collecting burned ash. When burning firewood in the beginning, firewood and air required for combustion are introduced through the Agungi, but when the full-scale combustion proceeds, the main inlet is blocked and the firewood is supplied with minimal air through a separate 'Air Inlet' provided at the bottom. Adjust the combustion time. Here, too, a small door mainly made of iron is installed to control the amount of air inflow. With this structure and air control, firewood burns slowly for 6 to 8 hours and supplies heat energy necessary for heating.

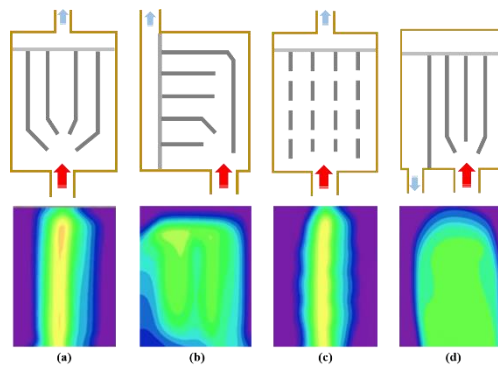


Fig. 6. Thermal Characteristic in Traditional Gudle [16].

The shape of the cut surface of the floor plan of the ondol has various shapes depending on the size of the room, the layout of the house, and the location of the chimney. Among them, Fig. 6 shows four types [15,16, 19]. In Fig. 6, the red arrow indicates the point where firewood is burned, and the gray arrow indicates the outlet of the

exhaust gas. The thermal characteristics picture below in Fig. 6 shows the thermal characteristics in which the heat generated in the combustion chamber diffuses at the same time according to the type of each heat channel. Among the patterns of the heat channel, (b) and (d) have the characteristics that the heat of the combustion chamber is transmitted evenly and quickly to the entire floor [16, 19].

The heat transferred to the stone of the room floor (Gudle) by heat conduction passes through the loess layer covered with a certain thickness on the stone and heat radiation occurs indoors. After a certain period of time, convection occurs in the indoor air by the heated floor. Through this process, the flame and heat generated in the combustion chamber accumulate heat in a number of stones and soil and discharge the heat into the room. In addition, smoke and carbon dioxide, which are harmful to humans, are separated from the room and discharged at the source. Eventually, the heat transfer path is formed to be long so that heat is sufficiently transferred to the stone or soil, so that the final combustion gas discharged to the outside becomes substantially no heat.

4.3 The principle of invention of TRIZ found in Ondol

In the approximate structure and operation of the ondol, the invention principles of TRIZ are found. What can be found can be distinguished by the purpose or use of the system, structural characteristics, and characteristics of the materials used. The principles of invention found were expressed within (*Number-Principle*).

4.3.1 Purpose or use characteristics

Ondol is a multifunctional technology system capable of both heating and cooking (*06. Multifunction*) and has features that incorporate different systems (*05. Consolidation*). The timing of heating overlaps with the timing of cooking, and the use of heat energy generated by less fuel for various purposes increases energy efficiency. In addition, by connecting the cooking system and the heating system, both functions are performed at the same time in one combustion process. Because the residential space and the burning space of firewood for cooking or heating are separated (*02-Extraction*), breathing difficulties do not occur during heating or cooking. In addition, when it is humid, such as during the rainy season in summer, dry the indoor space, the wall made of soil, or the soil of the roof by using ondol.

4.3.2 Structural features

The flame, heat, and smoke generated by burning firewood in the cylindrical combustion chamber spread into the inside of the sphere as it passes through the 'Bunumgi', a narrow area formed toward the room. At this time, heat spreads rapidly by the 'Venturi Effect' (*37-Thermal Expansion*). This principle is applied so that, unlike a fireplace, smoke including heat rises vertically to the chimney and is not discharged but separates and spreads fire (heat) horizontally through a number of passages (*17-Dimension*

Change). In addition, it uses some of the high-temperature heat or flame generated in the combustion chamber, but it has a structure that transmits only the heat for heating to the room and passes the smoke (*02-Extraction*). In order to distribute heat evenly to the floor of the room, the high heat generated in the combustion chamber is quickly separated into a number of heat channels so that the high temperature heat is not transferred locally to a specific location of the 'Stone Slabs' (*01-Segmentation*). In addition, in order to control the intensity and combustion time of thermal power, the thermal power is controlled by controlling the amount of air flowing into the combustion chamber through the air inlet separately from the main inlet where firewood is injected (*03-Local Quality*). During the combustion of firewood, long grooves are formed under the bottom of the combustion chamber through the smooth inflow of air, so that air is transferred smoothly to prevent smoke from incomplete combustion in the combustion process (*10-Preliminary Action*). The deepest groove is formed to prevent cold air from flowing into the orbs from the chimney so that the cold air stays there (*11-Preliminary Compensation*). In the process of making the indoor floor, the stones are filled with ocher to prevent smoke from entering (*24-Intermediate*). In addition, fine red clay powder is sprinkled in the construction process to fill the cracks caused by cracking as the loess is dried, so that smoke does not enter even if a fine crack is created (*25-Self-service*).

4.3.3 Characteristics of materials and by-products

As for the core of the ondol, soil and stone are the most inexpensive or free resources in most areas (*27-Cheap Short Life*). In Ondol, this is used in combination (*40-Composite Material*). In general, heated stone absorbs heat until it becomes saturated, and releases heat when it becomes saturated. Soil generally functions to block heat. The stones that make up the spheres have a heat storage function that stores the heat produced in the combustion chamber. The more these stones, the more heat can be accumulated and utilized. The door installed at the entrance to the cooking pot or the combustion chamber is made of iron. For other ingredients, water for kneading the loess becomes the material for making ondol. When the firewood, which is a source of heat in the heating system, is not completely burned, it creates new problems. Exhausting hot heat and smoke through a chimney can become a source of air pollution. The result of incomplete combustion is smoke and soot. In the case of good combustion, light and heat energy are generated and finally ash remains. Ondol has two air supply channels in the combustion process and has a structure in which sequential combustion occurs in one direction, so that it acts close to complete combustion. Most of the high-temperature heat is transmitted for indoor heating, and the exhausted gas has little heat. There is no problem with direct contact with the smoke from the actual chimney. Most of the combustible materials that are burned have the characteristics of a new material in which most of the combustible material is burned and the remaining ash is recycled and reused. Most of the time, it is used both as a material for planting or composting. Ondol has a quite simple structure with little need for repair if there is no change in the used soil or stone, or if there is a big problem, it can be reused and recycled even when the

ondol is dismantled in case of collapse or reconstruction of a house. In such a process, no special external energy is input.

4.4 Sustainable development, circular economy, eco-friendliness, suitability of appropriate technology

Various invention principles can be discovered in such an ondol system, and it has practically maintained the basic structure for thousands of years and has played a role as a link of circular economy in the ecosystem of the natural environment of rural Korea. The principle of the invention is about a principle for solving a certain problem, and a system in which several invention principles are applied in combination can be regarded as a technical system with high ideality. Ondol is a kind of optimized system that minimizes fuel and has the characteristics of an efficient and healthy heating system. In addition, it solves the heating and cooking problems in rural areas of Korea and has the characteristics of economically superior appropriate technology by being maintained and used without substantial modification for a long time. Such an ondol system can be summarized as Table 3 with TRIZ's MST.

Table 3. Characteristics of Ondol from the MST Perspective.

Level \ Time	Past (Before Use)	Present (In Use)	Future (After Use)
Super-System (Macroscopic Ideality)	By-product, waste (X)	Environmental pollution (X) Target: air, water, soil	Environmental pollution (X) Target: air, water, soil
System	Ondol construction/simplicity of structure Knowledge conveyed orally Transfer to construction demonstration	Smoke and ashes Recycle (O) No Cost	100% Dismantle (O)
Sub-System	Stone, soil, water, combustion chamber door (metal) Easy pretreatment of materials Local free resources	Easy to repair and replace parts Object: Stone, soil No Cost	Easy to disassemble (O) Material recycling/reuse (O) No Cost Hazardous/Danger (X)

Ondol does not cause harmful effects or side effects to the user or the surrounding environment in the preparation process for problem solving and the entire process during and after use. All materials to build the system are virtually free resources locally in Korea. Even after the system is dismantled, it can be reused and recycled for various purposes in the area. There is no additional economic loss as a result. In addition, the high-temperature heat generated during use is not discharged into the atmosphere, and the ash remaining as a by-product is sprinkled on the paddy field and is usefully used as fertilizer for crops, thus playing a positive role in the circulation of resources and the ecosystem. These ondols are a living culture that has been used throughout Korea for

more than 2000 years. Ondol also has a historical record of being used as a source of heat to make greenhouses and grow vegetables in the winter of 1450 [25]. Today, ondol retains its basic principles of the early days, and is being slightly improved due to changes in the type of modern housing and the heat source used. Recently, retired people in Korea began using double-decker ondol to heat for longer with minimal firewood as they built houses in the countryside. However, duplex forms such as Fig. 7 have already appeared in the literature of the late 17th century [26]. At that time, it is inferred that the structure was not widely distributed due to its complexity and difficulty to produce. Currently, the use of firewood tends to be reduced to protect forests and trees, so modified ondol using alternative heat sources is widely used. In other words, gas, oil, and electricity are used as new sources of heat while maintaining the floor heating system, and the heat is mainly transferred to the floor of the room by heating water pipes, making it installed in most Korean houses [22]. This approach is practically the same as ondol, with the concept of accumulating heat in water instead of stone and then slowly using heat. Also, heating water for heating is done in individual homes, but in the case of cities, hot water is supplied to each house using heat generated from cogeneration plants.

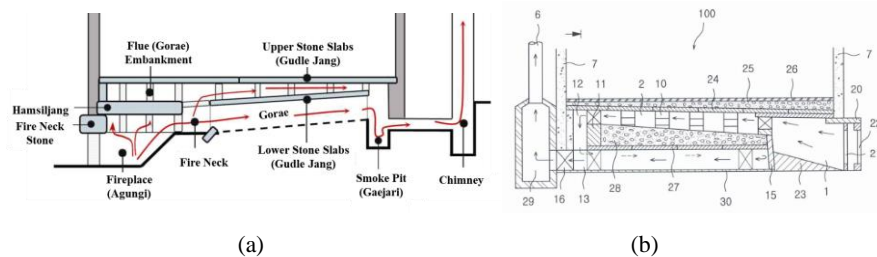


Fig. 7. Ondol with double structure Gudle [26, 27].

The ondol system is attempting to solve the housing heating problem in Korea and the world through various applications and applications based on the basic principle. In 2001, the International Ondol Society (<http://www.internationalondol.org>) was established, and academically in-depth research is being conducted. Also, on April 30, 2018, 'Ondol Culture' was registered and managed as Korea's National Intangible Cultural Property No. 135. Efforts are still being made to increase the efficiency of ondol, and Fig. 7's (b) is a patent registered in Korea in 2014 [27].

Ondol is a technology system where many TRIZ inventions are discovered, and the level of ideality is high. It has also been verified through long-term use and can be seen as an example of excellent Appropriate technology from a macro perspective. It also features an eco-friendly, high-efficiency heating system that simultaneously incorporates the concept of a circular economy and sustainable power generation. It can be said that it is not a solution for temporary problem solving at a specific time or place, but a true macroscopic Ideal Final Result to have initial functions and performance without creating new technical problems even for long-term use.

5 Conclusion

The basic purpose of sustainable development is for humans and nature to maintain healthy vitality. Once incorrectly made products continue to adversely affect the natural ecosystem during its existence. However, appropriately designed products have the characteristics of Circular Economy and eco-friendly. The key parameters of design for sustainable development are whether harmful effects are caused by time-flow interactions with various elements of the environment in which the product is used. Korean Ondol has been used for a long time, but there were no special technical problems or harmful effects, and it has economic feasibility. Partial technology optimization is an example of appropriate technology that exists depending on the type of house but still maintains the basic principles. The key feature is that the interactions with the components, materials, and environment that make up the system do not have any real harmful consequences in time-driven MST analysis. And it suggests what should be considered and what approach should be taken in the design of appropriate technology for sustainable development. In DfX-based conceptual design, in a situation where problem-solving through overall system function analysis and resource utilization is required, resource analysis based on MST of components becomes the core procedure of design realizing a practical circular economy.

However, in the case of Ondol, the timing of the actual initial conceptual design or the designer is unknown, and a more diverse case analysis is needed as a characteristic analysis by follow-up observation. In addition, in the case of having a complex system configuration in a more complex environment, there may be limitations in applying the analysis and approach presented in this study as it is when a problem situation needs to be resolved within a relatively short development period. However, it will be possible to serve as a guide and direction of conceptual design to achieve a macroscopic ideal for sustainable development.

References

1. Jouni Korhonen, Antero Honkasalo and Jyri Seppälä, "Circular Economy: The Concept and its Limitations", *Ecological Economics*, 143, 37-46 (2018).
2. P. Morseletto, "Targets for a circular economy," *Resources, Conservation and Recycling*, 153, 104553 (2020).
3. A European Strategy for Plastics in a Circular Economy 2018, European Commission (2018).
4. Greenpeace Plastics Report (2019).
5. The Evaluation and Application of the TRIZ Method for Increasing Eco-Innovative Levels in SMEs (2017).
6. Davide Russo and Christian Spreafico, "TRIZ-Based Guidelines for Eco-Improvement", *Sustainability*, 12(8), 3412 (2020).
7. Lee, S. G., "Sustainable Development and Technology Development", *Bulletin of Korea environmental preservation association*, 14(8), 2-3 (1992).
8. <https://paulpolak.com/the-death-of-appropriate-technology-2>

9. https://blog.naver.com/kipa_ipsharing/220782294638
10. Kuo, T. C., Huang, S. H., and Zhang, H. C., "Design for manufacture and design for 'X': concepts, applications, and perspectives", *Computers & Industrial Engineering*, 41(3), 241–260 (2001).
11. Dombrowski, U., Schmidt, S., & Schmidtchen, K., "Analysis and Integration of Design for X Approaches in Lean Design as basis for a Lifecycle Optimized Product Design", *Procedia CIRP*, 15, 385–390 (2014).
12. CLIMATOLOGICAL NORMALS OF KOREA (1981~2010), KOREA METEOROLOGICAL ADMINISTRATION SEOUL, REPUBLIC OF KOREA (2011).
13. <https://www.lexico.com/en/definition/ondol>
14. The Federation of Korea Culture Center. <https://ncms.nculture.org/house/story/6602>
15. Park, J. J., and Lee, K. H., "Numerical Analysis for Thermal Characteristic in Traditional Gudul", *The Society of Air-conditioning and Refrigerating Engineers of Korea*, 107-107 (2005).
16. Rhee, S. H. and Rhee, G. H., "Analysis for Thermal Transfer in Traditional Ondol(Gudle)", *Proceedings of the Korean Society for Agricultural Machinery Conference*, 11(2), 213-216 (2006).
17. Sustainability Report, Hanwha Solutions Chemical Division (2015).
18. Joan Manuel F. Mendoza, Maria Sharmina, Alejandro Gallego-Schmid, Graeme Heyes, and Adisa Azapagic, "Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework", *Journal of Industrial Ecology* (2017).
19. Rhee, S. H. and Rhee, G. H., "Heat Flow Characteristics of Traditional Ondol (Gudle) by Numerical Analysis", *Korean Society for Agricultural Machinery*, vol. 49, no. 1, pp. 17–22, (2007).
20. Shqipe Buzuku and Iuliia Shnai, "A systematic literature review of TRIZ used in Eco-Design", *Journal of the European TRIZ Association 02-2017 (04)* (2018).
21. Kim, J. Y., "A Study on the Development of Guideline and Application for Sustainable Design", Korea Polytechnic University (2011).
22. Hong, H. G., Kim, S. H., "Method and Analysis of Dynamic Simulation for Ondol Heating", *Korean journal of air-conditioning and refrigeration engineering*, v.22 no.6, pp. 375-382 (2010).
23. Chun, C. H., "The Other 90%, Warm Technology, and the Best Solution: A Critique of the Appropriate Technology Movement in South Korea", *Journal of science & technology studies*, 14(2), 127-164 (2014).
24. Winner, L., "The Whale and the Reactor: A Search for Limits in an Age of High Technology", *Chicago: University of Chicago Press* (1986).
25. Chun, S. U., *A Mountain House Cookbook*, <https://if-blog.tistory.com/724>, 1459.
26. Chung, Jung-Nam, "A Change of Awareness on the Ondol System and Architectural Seeking for Increasing Heating Efficiency since the 18th Century Joseon Society", *Journal of architectural history*, 27(3), 15-26 (2018).
27. Mun, J. N., "Thermal Storage Ondol Gudle with Duplex Structure", KR Patent, No. 10-1374432 (2014).