Development, Application and Carbon Emission Measurement of Architectural Steel Panel based on Parametric Design

BY

WOOSEOK KIM*

SYNOPSIS:

Recently, for the purpose of differentiating building design, there has been a growing demand from architects, designers and construction companies for the implementation of irregular shaped design – ex) parametric design – panels.

In this paper, some cases of design panels that can be implemented through laser cutting, bending and bolting using flat materials such as steel sheets and pipes will be introduced. The important thing is that such design panels needs to be implemented without mold making, press forming, or welding - from a realistic perspective, such as production cost and constructability.

As a representative example, the author will introduce the case of exterior remodeling of a department store in Daejeon, Republic of Korea. And it mainly describes a process of replacing and applying specification with 1.2mm thickness of steel sheet, which was previously designed with 3.0mm thickness of aluminum. The author will also present the practical eco-friendliness of steel-based building materials by measuring and quantification of carbon emissions compared to aluminum panel.

Keywords: Building design, Exterior steel panel, Parametric design

* Senior Researcher in Design Solution for Architectural Interior and Exterior Steel Products – Steel Solution Research Lab., POSCO, Incheon, Republic of Korea

1. Introduction

1.1. Background and Purpose

The requirements of customers and society for steel companies are gradually diversifying. In order to solve the increasingly demanding market, customer, and social needs, some steel companies have recently adopted combination of traditional scientific management method and design management.

In particular, in the existing paradigm of simply selling primary products such as coils, rear plates, and wires, the need to use design is recognized as a strategy to expand product sales and create new demand by satisfying the needs of various stakeholders in supply chain. However, it is necessary to establish a design process considering the business environment of the material company, given that design has been used mainly by companies that produce consumer goods or provide B2C services, and that design has been used from a simple skill or outsourcing perspective due to low understanding of design and operation of a small number of professionals.

Meanwhile, since the Paris Agreement in December 2015, in which 195 countries around the world promised to reduce greenhouse gas emissions to respond to the climate crisis, demands for carbon neutral by steel companies have risen sharply. To this end, it is necessary to strategically approach not only footprints corresponding to carbon emissions in the production process but also handprints corresponding to positive contributions by reducing carbon emissions in the post-shipping stage. In particular, in the construction field, since primary steel products are processed and used as various parts such as structural materials and interior materials, quantification, improvement efforts, and active promotion at the handprint level are needed.

Therefore, this study proposes a design process that can be used by steel companies based on design thinking and suggests the direction and method of design usage in steel companies through the case of steel exterior panels applied to the remodeling project of a department store in Korea. In addition, I would like to present an example of handprint improvement demonstration by comparing and quantifying carbon emissions of steel materials actually applied - compared to aluminum materials originally considered in the remodeling project. This would verify that steel companies can also apply design from the perspective of work process to solve various problems required by customers and the market, and suggests that steel companies can contribute to social carbon reduction and carbon neutral.

1.2. Research Methods and Subject

The method and system of this research were conducted as follows.

(1) In the field of interior and exterior materials of architecture, customers' needs to differentiate the façade design through metal materials were considered. Since aluminum has been widely used as a finishing material, it is necessary to present to the market and customers that steel has possibility to replace aluminum in various aspects such as processability, price, and quality to create new demand for steel industry

(2) A design process based on design thinking was proposed. Based on the fact

that design thinking is a dynamic balance between perfect proficiency based on analytical thinking and creativity based on intuitive thinking, we propose a process to present solutions and create win-win values as soon as possible.

(3) A case in which steel panels were applied instead of aluminum was considered by applying the process to an exterior remodeling project in Korea. Through the case that POSCO responded to each of the processes, the possibility that steel can be used for the exterior of department stores, one of the representative buildings of commercial buildings, was presented.

(4) Carbon emissions were quantified and compared between when aluminum was applied to the project and when actual steel materials were applied. Originally, the designer who participated in the project designed with 3t-thick aluminum and changed it to 1.2t-thick steel by POSCO's response. In this study, the possibility of improving the handprint of steel materials was demonstrated by quantifying carbon emissions in each case.

2. Customers' needs diversification and design process suggestion

2.1. Material trends in interior and exterior design regarding metal

In the architectural metal product - interior and exterior mainly - market, various shapes of atypical buildings and surfaces using digital fabrication have begun to appear. Atypical buildings such as the Bilbao Guggenheim Museum in Spain, Dongdaemun Design Plaza in Seoul since 2010, and Songdo Tribowl in Incheon require 3D curved or complex shape implementation. And for this, aluminum panels were mainly used in terms of molding, ease of processing, and lightweight.

[Figure 1] Guggenheim Museum(Bilbao, Spain), Dongdaemun Design Plaza (Seoul, ROK), Songdo Tribowl(Incheon, ROK)

The background of this phenomenon is that the end user demands to differentiate his building design in terms of its mass or surface, the architect needs to create new shapes and space programs, and new techniques such as parametric design are being developed.

The reason why aluminum is being adopted as exterior finishing is that its softness in terms of strength enables easier forming and processing, as well as its high corrosion resistance above a specific grade. However, its softness could lead to weaker structural rigidity, so it should be generally used in a small size, or with a high strength supporting structure. In addition, it is pointed out that eco-friendly

advantages - compared to steel - are insufficient, regarding that aluminum exhales more carbon - in phase of producing - than steel and it has lower recyclable rate.

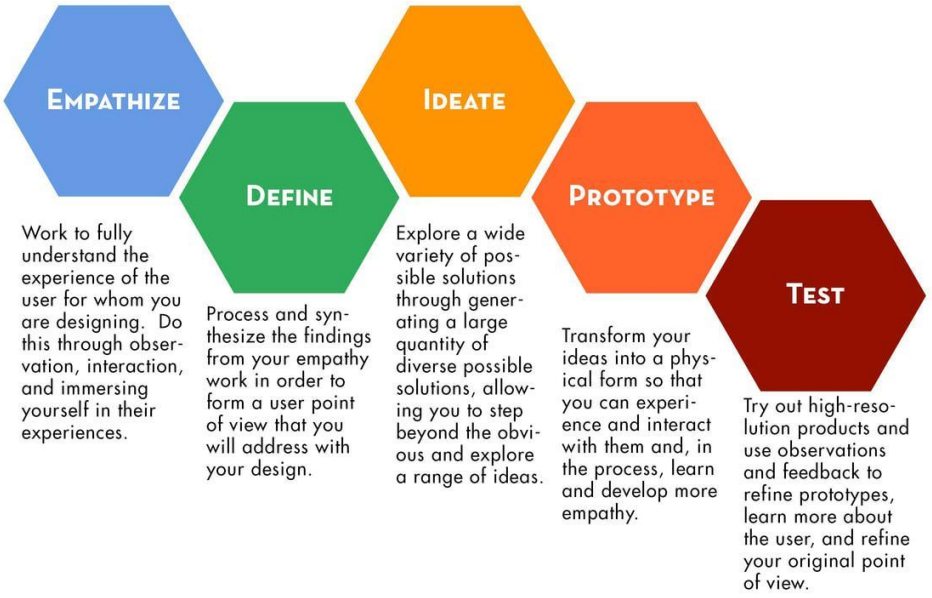
On the other hand, in order for steel materials to meet those needs of creating aesthetical value, it can be inferred that creative ideas and solutions for various stakeholders' suggestions.

2.2. Proposal of work process based on design thinking

Design thinking generally refers to the thinking process and method of enabling innovative design by creatively solving the problem at hand, and is also a "new paradigm" of education and management that leads to innovation, but the underlying perspective is to balance the perfect skill based on analytical thinking and creativity based on intuitive thinking. New ideas and knowledge that lead to the creation of a company's value come from the harmony of search-based reasoning and intuition as well as its solid rules and logic of experience. In addition, from the perspective of a multidisciplinary approach that combines technologies such as design, engineering, economy, humanities, and social sciences, if any problem or idea continues to be replaced, combined, and mutated through communication with many experts in the company, it will eventually flow to problem solving and development of ideas.

Korean steelmaker P has been producing steel products for more than half a century since its foundation in 1968, securing global technological superiority and experience assets in the field. However, combination of creativity based on intuition as well as experience-based logic is required to cope with customers' increasingly diverse and complex needs, suggesting that design thinking is necessary. Design thinking to be introduced and applied for this research is an overall business process that induces the market or customer to adopt steel products through prototyping to respond to new types of demands presented by the market or customer. In this research, I'd like to propose a new work process based on the five-step model by Stanford's D School, which is recognized as one of top educational institutions regarding design thinking. First of all, the process and characteristics of design thinking presented by D School are as follows.

2.2.1. D school’s design thinking Process



[Figure 2] Design Thinking Process Model suggested by D School, Stanford Univ.

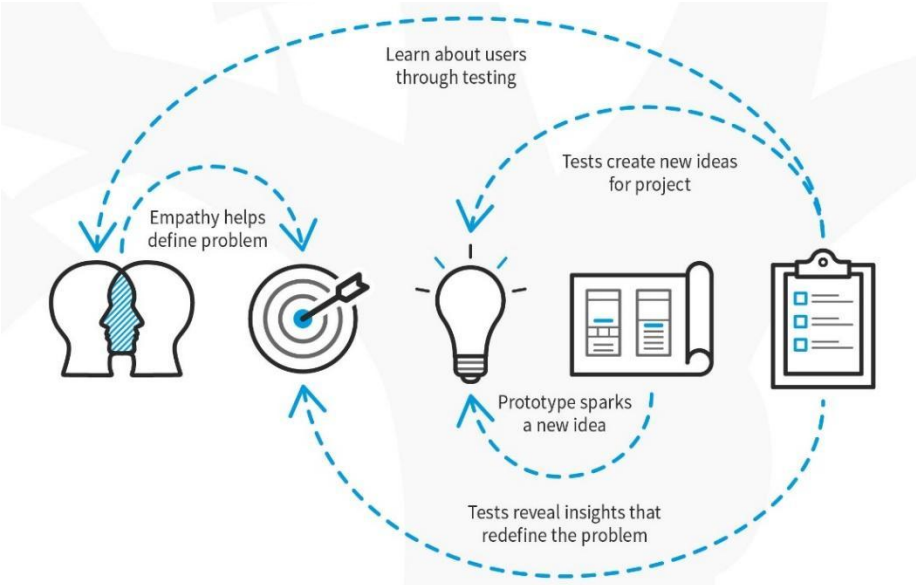
EMPATHIZE : The first step in the design thinking process is to obtain a sympathetic understanding of the problem to be solved. To this end, methods such as observing words and actions between stakeholders related to the project or participating in mutual discussions are mobilized.

DEFINE : In the second step, the information analysis collected in the first step defines the key issues or requirements that the project faces.

IDEATE : Third step is to devise various ideas from a new and original perspective that breaks stereotypes, either spontaneously or intuitively, with ideas that can solve the core of the problems defined above.

PROTOTYPING : It is to make invisible ideas into ‘visible products’ with physical materials that can be prepared in a short time.

TEST : It is showing the ‘prototype’ to stakeholders to solve the problem, listening to their reactions, and correcting if there is anything needs to be so.



[Figure 3] Design Thinking: A Non-Linear Process suggested by Interaction Design Foundation

Meanwhile, design thinking process is a nonlinear process. In other words, prototyping and testing, for example, can lead to defining new problems, or can lead to creating new ideas.

2.2.2. Proposal of work process for steel construction - in terms of interior and exterior material suggestion

The scope of proposing the work process based on design thinking is for steel companies trying to solve customers' needs or problems. Therefore, 'empathize' in the existing model can be integrated into 'define' as a simple and obvious step to define customers' needs or problems. In addition, since the 'test' is an act that takes place almost simultaneously with 'prototyping' - proposing the results of the prototyping to stakeholders - so it can be integrated into 'prototyping'. Finally, in this research, 'optimization' step is additionally proposed. In the step of 'optimization', optimization activities in each aspect, such as shape, surface, structure, and construction method, are carried out to apply steel to an actual building. As a result, the process model that synthesizes these proposals is as follows.

[Figure 4] New Work Process Proposal for Steel Company Regarding Construction Material

DEFINE : The needs of various customers in supply chain are to be identified, analyzed, and defined. Among them, it is necessary to define key requirements and issues in order to ensure that steel can be supplied at an accurate timing.

IDEATE : In the second step, variety of ideas and solutions to address key problems and requirements should be derived. It should strive to come up with a solution from a new perspective by synthesizing new and original ideas that are "not filtered" from various stakeholders such as distributors, secondary processing companies, painting or coating companies, as well as designers.

PROTOTYPING : It is suggested that "rapid" should be attached and operated as "rapid prototyping". Since construction projects are generally limited in time and cost, and decision-making as soon as possible is a way to save time and cost, steel companies need to propose to stakeholders and receive feedback through prototyping as rapid as possible. And if necessary, another prototyping reflecting feedback can be performed.

OPTIMIZATION : Finally, the optimization step is to optimize various conditions such as shape (producibility, etc.), surface(corrosion resistance, paintability, etc.), structure(wind pressure performance, etc.), construction(transportation, stacking or

storing for a while , construction process, etc.) so that the steel can be actually applied to the project. In order to replace competing materials such as aluminum and secure new demand for steel materials in terms of exterior materials, it is necessary to meet and monitor stakeholders' demands throughout the whole process.

3. Case Study: Exterior Remodeling Project of a Department Store

3.1. Project Overview

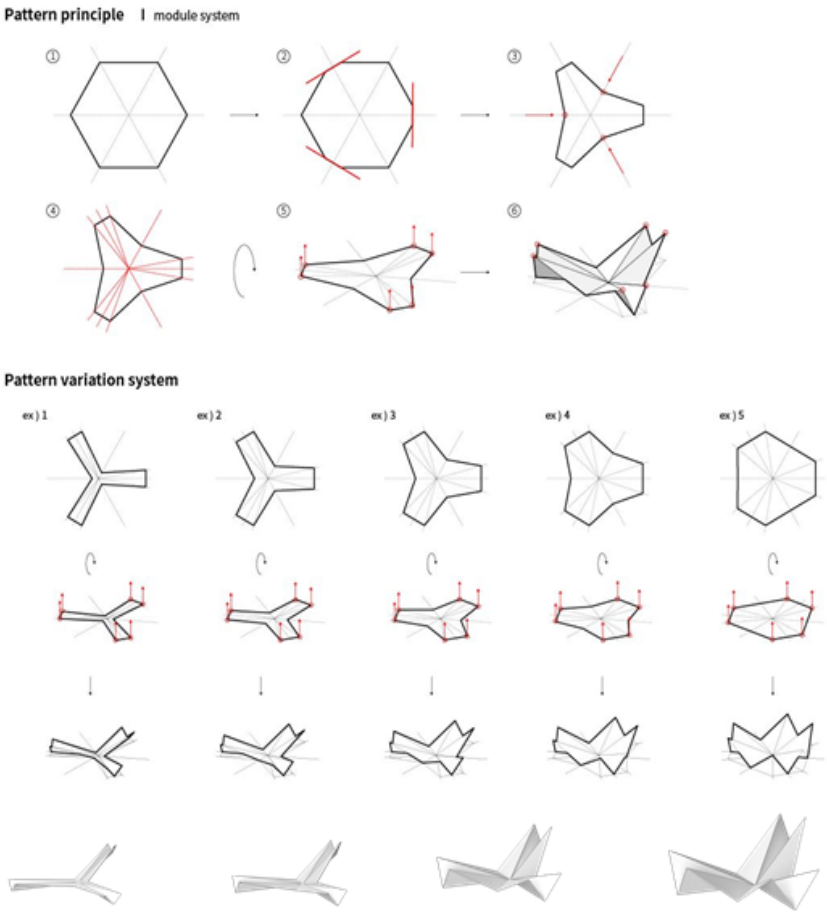
The case project began when architect A, who had been in touch with POSCO won design competition of exterior remodeling for a department store in Daejeon, Republic of Korea. And A inquired if the design originally designed with aluminum could be implemented with steel. For creative design, A utilized parametric modeling tool - also known as digital fabrication techniques - to design unique facade consisting of exterior panels in repetitive elements of slightly different shapes and sizes.

Following the new work process, experts in diverse fields in POSCO gathered instantly trying realize the A's design in shape, secure surface and structural performance such as corrosion resistance and wind pressure, in order to apply P's steel material to the project.

3.2. Application case by new work process

3.2.1. Define

Architect A envisioned the concept of repeating petal-shaped units surrounding the department store, and intended that individual petal-shaped patterns were created by the following principals.



[Figure 5] Pattern Principle and Variation Proposed by Architect A

This was made by processing flat metal materials in a molding method similar to origami and re-dimensionalized them, and the results of re-dimensionalization of petal shapes were derived through the same molding method. Architect A initially designed aluminum to produce more than 5,000 units up to 3 meters in length, each with slightly different shapes and sizes. But A then decided that different molds were inappropriate regarding cost and productivity and asked POSCO if its steel products could efficiently be implemented.

POSCO confirmed such requirements and defined the exact needs for the project. It was thought that steel had potential to create a light atmosphere while surrounding the entire building surface by implementing a large steel panels with relatively thin thickness using the rigidity of steel compared to aluminum.

3.2.2. Ideate

Various opinions were exchanged to realize the requirements. First, the idea based on logic of experience rules was to produce using large press molding equipment, or to bend it into two to three types of curvature like the case of Dongdaemun Design Plaza, Seoul. In addition, as steel products are applied as exterior materials, it was necessary to prevent corrosion that may occur depending on construction methods or climate environments, and to ensure that the final

product is structurally sound. In particular, it was suggested to apply POSCO's PosMAC the aluminum-magnesium-zinc ternary alloy plated steel product, and in some cases, it was suggested that a separate surface treatment may be necessary after molding.

However, the idea of the molding method presented earlier was regarded inefficient in terms of manufacturing, which requires more than 5,000 units of different sizes to be implemented by press molding, and productivity decline due to the relatively slow molding speed of the curvature bending method. The project had a target period and cost range, and it was needed to consider prefabrication. Above all, considering that the general width size of steel coils is 1,500mm, it was pointed out that there is a limit to creating the unit from a single flat material.

On the other hand, the limitation of the width length rather induced the idea by intuition, and since the target - largest - size is 3,000mm while the implementation range is 1,500mm, the idea of "splitting" one unit was inevitably derived. In other words, the possibility of utilizing the planar characteristics of steel materials by dividing them into individual planes and approaching them from the perspective of forming a unit by integrating them has been embodied. And as a processing method, laser cutting and bending were discussed.

Another idea "bundle with support structure" was derived. It was thought to be effective in a way of realizing design synthetically along with not only steel pipes products but also steel sheets. Ideas by logical and intuitive thinking were derived and interacted without limitation through brainstorming, capturing clues to problem solving.

3.2.3. Prototyping

3.2.3.1. First Prototyping

The ideas and adoption derived from previous steps were collected and integrated, and the first prototype was produced in collaboration with a secondary processing company and a painting company. The unit divided and processed by the manufacturer adopted a method of fastening using bolts - not welding - after painting for corrosion resistance on the surface and reducing on-site construction ratio. In addition, based on the idea derived in the previous steps, the supporting structure was presented together.

The first prototyping was conducted by inviting not only architect A but also the final client together, so that many stakeholders gathered in one place could exchange possibilities and complements by unrestricted discussions.

[Figure 6] First Prototype of Exterior Steel Panel System

3.2.3.2. Second Prototyping

Based on the feedback derived at first prototyping, a secondary prototyping consisting of three types was conducted reflecting actual size of panel modules. Reflecting advanced idea for connecting and fastening, bolts used to be exposed outside were hidden at the secondary prototyping. And lights were attached and tested in order to verify the possibility of media facade at night time.

[Figure 7] Second Prototype of Exterior Steel Panel System

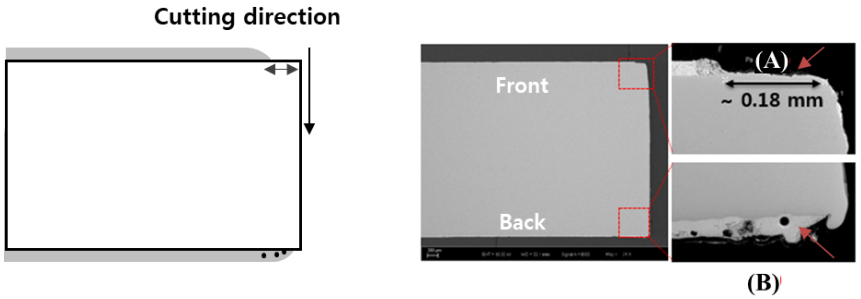
At the time, diverse questions, answers, and advice from various stakeholders were exchanged, and owing to the secondary prototyping, the steel products proposed by POSCO were finally reflected to the project, ensuring link to sales.

The panel part was 1.2mm thick PosMAC sheet, and the supporting structure was PosMAC pipe of 1.6mm and 2.3mm thickness.

3.2.4. Optimization

3.2.4.1. Laser Cutting

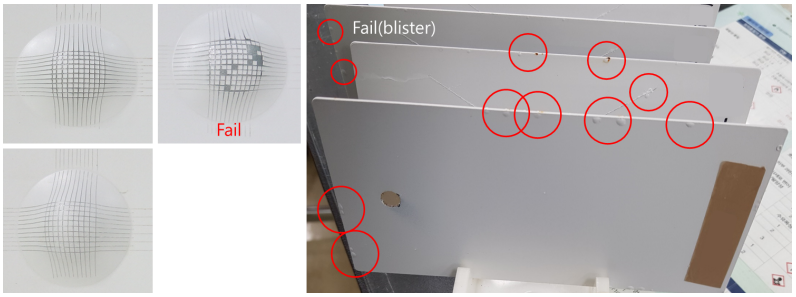
As previously considered, for the implementation of panels of various shapes, it was intended to contribute to securing precision by adopting laser cutting and bending methods. However, the coated layer on the steel surface could be lost due to heat generated during laser cutting, which is expected to cause corrosion during the manufacturing and construction processes, so a plan to ensure proper corrosion resistance was discussed after laser cutting and bending.



[Figure 8] Zoom Image of Steel Cut Surface After General Laser Cutting

3.2.4.2. Coating and Painting Quality

In addition, it was pointed out that the powder coating or PVDF coating was considered for the painting after processing, but the quality of the painting was required to be checked. To this end, samples coated with each painting method were requested to the secondary processing company and painting company to verify whether they could pass paintability test such as Ericksen test, salt spray test, etc,



[Figure 9] Reliability Test of Painting Samples for Exterior Panels

3.2.4.3. Structure Performance

Wind-resistant pressure test was conducted to verify whether panels and structure could exist stably withstanding harsh climatic conditions such as typhoons in areas where they would actually be constructed. Based on the largest petal-shaped panel, the test was conducted by manufacturing a model of the same size and structure as the actual installed panel system, and the experiment showed that it could withstand wind pressure 1.5 times more than the required wind pressure standard.

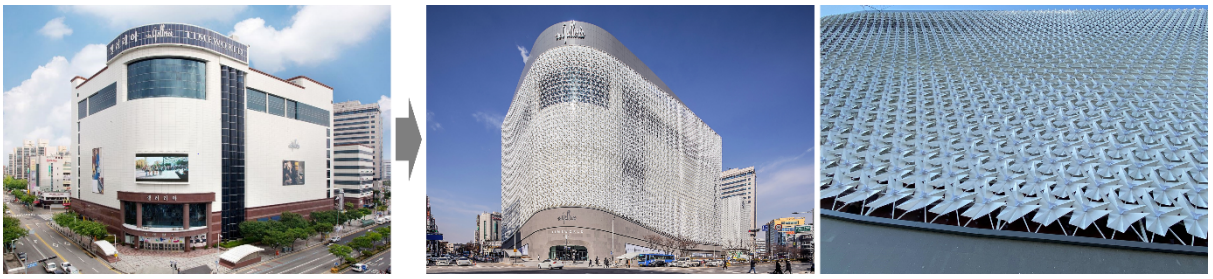
[Figure 10] Separated Panel Unit, PVDF Coating, Wind Pressure Test

3.3. Achievement

Through the above process, 500 tons of PosMAC were supplied to the project, and white steel petals were wrapped around the exterior of the department store, which is the representative of the commercial building, during the day and media facade at night.

POSCO could get a new kind of portfolio of PosMAC products - which had been mainly used for solar energy structures - enabling more active marketing and advertising so that they could be applied to interior and exterior construction materials.

In addition, it was an opportunity to see not only the advantages of steel materials that can realize design intentions reasonably and beautifully, but also the competitive cost and structural performance compared to aluminum, and solution-based R&D and marketing activities supported by POSCO.



[Figure 11] Exterior Transformation (Galleria Timeworld, Daejeon, Republic of Korea)

4. Quantification of CO_2 Emissions and Analysis of Societal Reduction

4.1. The Necessity of Societal Reduction of CO_2

As the role and responsibility of industries responding to climate change are emphasized, the demand for carbon neutral, especially in the steel and chemical industries, which emit a large amount of greenhouse gas, is increasing. Specifically, it is required to present convincing environmental performance and plans regarding "green" activities being promoted by steel companies.

However, there is a limit to the lack of global standards for "green" in steel industry. In other words, in order to effectively promote the "green" steel activities, a unified definition of "green" containing specific and quantitative concepts is needed.

The views of the government, major institutions, and global steelmakers on "green" are generally divided into production or use phase perspective, and majority of customers are mainly interested in production phase - such as scrap use ratio and carbon emissions in blast furnace process.

However, the worldsteel insists on paying attention to both production and use phase, and POSCO also agrees. In other words, the concept of "green steel activities" including the entire life cycle is necessary.

Accordingly, POSCO established a new concept of green products including the entire life cycle of steel production and use phase. The definition is "Products that contribute to reducing carbon footprint or reduce environmental burden" and are classified into three types in detail: Life cycle perspective (production, use) and

emission perspective (carbon, etc.). Descriptions for each type are as follows.

Type	Category	Description
Minimizing Footprint	Using recyclable material	More than 30% ratio of scrap usage
	Using renewable energy	RE certified electric usage
	Low carbon process	Certification for 'Low carbon product' by Govt. or satisfying EU Taxonomy standard
Maximizing Handprint	[Material] CO_2 reduction	Effect by replacing aluminum, cement, etc. with steel
	[Industry] Material for low carbon industry	Steel supplying for eco-friendly industry (solar, wind energy, etc.)
	[Process] Skipping	Achieving efficiency in clients' process control
	[Efficiency] Energy efficiency improvement	Achieving efficiency in clients' energy control
	[Disposal] Durability improvement	Life extension by higher anti-corrosion and strength
Reducing environmental stress	Reducing toxic substance	Contribution for toxic substance emission

[Table 1] POSCO's Green Product Types and Descriptions

According to ISO 14067(2018), carbon footprint is the sum of greenhouse gas emission and removals in a product system expressed as CO2e and based on an LCA using the single impact category of climate change.

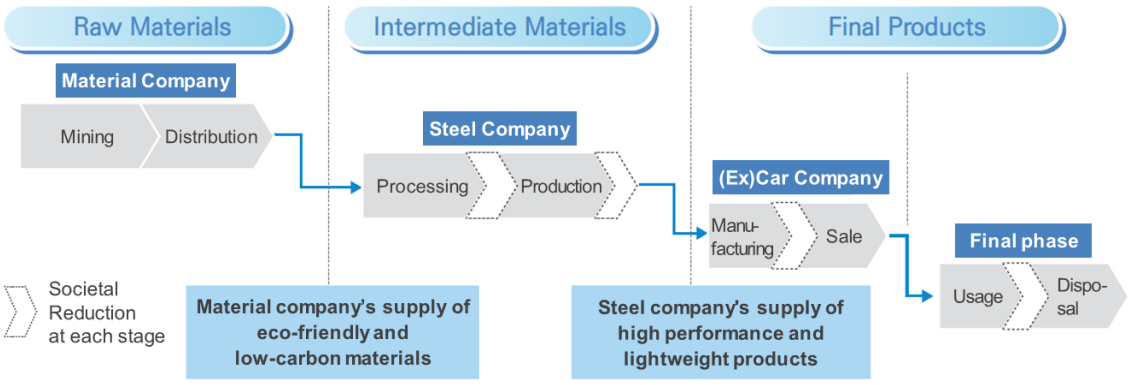
On the other hand, carbon handprint is a concept presented in 2012 by Greg Norris - professor at Harvard University, co-director of Sustainable and Health Initiative for Net-positive Enterprise MIT and Harvard Public Health Center.

While carbon footprints are all the negative consequences of maintaining an individual or organization - total "cost" to our existence, handprint is the opposite. It's a positive change-making contribution, including reducing the footprint of oneself or others. In other words, handprint represents the benefits of what we are. Not only personal daily activities such as buying local food, reducing meat consumption, and using energy-efficient light bulbs, but also advanced engine and lightweight car body developing activities that increase car fuel efficiency can be examples of handprint improvement activities.

According to carbon handprint guide(2018), it is also said that carbon handprint is an indicator of climate change mitigation potential. It describes the greenhouse gas emission reduction in a customer's activities that occurs when the customer replaces a baseline solution with a handprint solution.

Category		Description
Direct emissions	Scope 1	Emissions that occur from sources that are controlled or owned by an organization
Indirect emissions	Scope 2	Emissions associated with the purchase of electricity, steam, heat or cooling that are a result of the organization's energy use
	Scope 3	Emissions that occur in the value chain of the reporting company, including upstream and downstream emissions
Avoided emissions		Emissions that can be reduced or avoided in life cycle by replacement of low-carbon, eco-friendly products and services produced by an organization

[Table 2] Greenhouse Gas Emissions Classification



[Figure 12] Societal Reduction in Value Chain Perspectives

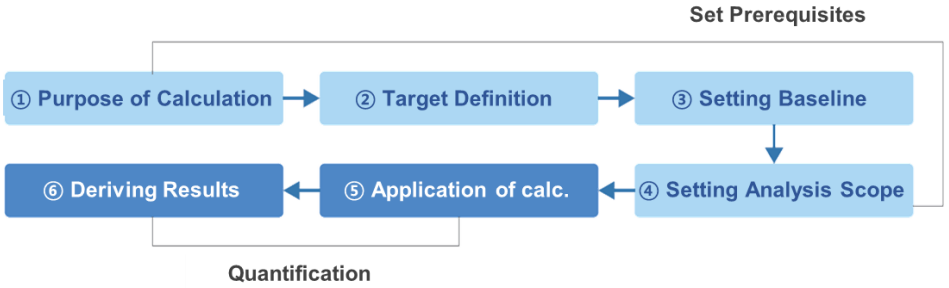
POSCO intends to appeal its "green" competitiveness by presenting quantifying carbon reduction amount in terms of societal reduction, as well as significant efforts in scope 1 to 3. The reason why societal reduction is particularly important is that it can supplement the limitations of the partial and disconnected approach of the workplace-oriented approach which covers scope 1 to 3.

4.2. POSCO's Societal Reduction Guidelines

Global companies refer to appropriate guidelines to systematically quantify and secure transparency when calculating and reporting societal reduction amount.

POSCO published Korea's first guidelines for joint use with Korean steel companies in November 2021. The guidelines were published jointly with Korea Business Council for Sustainable Development and Korea Iron and Steel Association by referring to ISO 14040, 14044, 14064-1, etc. The purpose of the guidelines was to expand discussions on societal reduction and to provide consistent guidelines for Korean steel companies to refer to and utilize.

The process of calculating the amount of societal greenhouse gas reduction consists of setting the objective of calculation, defining the target(product that functions as societal reduction), setting the baseline, setting the scope of analysis, applying the calculation methodology(calculating the carbon emission unit and usage by material) and deriving result.



[Figure 13] Basic Procedures for Calculating Societal Reduction

Baseline is subject to specific criteria or comparison for calculating societal reduction. In other words, it refers to a target product that is replaced through a product with a social reduction function. Parametric design panel for example, the

aluminum(3t thickness) previously designed by the architect A is baseline, and POSCO's steel(1.2t thickness) is the product with societal reduction function. Therefore, the societal reduction amount per product unit can be said to be the value obtained by subtracting the emissions of the calculated target from the baseline emissions.

Societal Reduction Amount(product unit) =
Baseline Emissions - Target Product's Emissions calculated
*Calculating each step from the perspective of the entire life cycle is needed

4.3. Quantification of Carbon Emissions and Societal Reduction Effects of Parametric Design Panel

In the remodeling project, aluminum with a thickness of 3T was originally designed, and as a result, it was converted to a HR-based coating product with a thickness of 1.2T, so the carbon emissions that was socially reduced by converting to steel compared to aluminum was calculated. Emission unit data was cited from British Building Services Research and Information Association(BSRIA).

① Purpose of calculation : Estimating the amount of societal GHG emissions reduction compared to baseline when using steel products for building exterior panels

② Target definition : 1.2t thick HR(hot-rolled) with zinc coating on surface

③ Setting baseline : 3.0t thick aluminum for the implementation of an atypical design - product commonly used as building exterior material

④ Setting analysis scope : Calculation of CO_2 emissions during the production phase

⑤ Application of calculation

	Emission unit ($kg \cdot CO_2e/kg$)	**Baseline (3t Aluminum)**		**Solution (1.2t Steel)**		**Amount of reduction**	**Reduction rate** (%)
		Usage (kg/m^2)	**CO_2 emissions** (emission unit x usage, $kg \cdot CO_2e/m^2$)	**Usage** (kg/m^2)	**CO_2 emissions** (emission unit x usage, $kg \cdot CO_2e/m^2$)		
Aluminum	9.18	14.5	133.11	NA	NA		
HR steel	1.07	NA	NA	16.6	17.76		
Zinc galvanizing	3.09	NA	NA	0.09	0.28		
SUM	ΣUsage x emission unit	-	133.11(A)	-	18.04(B)	115.07(A-B)	86.4

[Table 3] Result of Calculation (emission unit cited based on BSRIA data)

⑥ Deriving results : 1,977 tons of CO_2e savings(86.4% reduction rate) by applying 1.2t steel(310 tons of CO_2e emissions) compared to 3t aluminum(2,287 tons of CO_2e emissions)

5. Conclusion

This research derived a process based on design thinking to suggest design application methods and implications to create new demand for steel companies in construction industry, and analyzed the case of POSCO's steel panel application for exterior remodeling project of a department store. In addition, the eco-friendly nature of steel compared to aluminum was demonstrated and presented through carbon emissions quantification. The conclusion of this research are as follows.

First, steel companies have been pursuing management models based on the traditional methodology such as six sigma, and tend to rely on design to cope with increasingly complex and demanding market conditions and customer needs. But since they use design partially, a comprehensive design process is required.

Second, a new work process was proposed in terms of design thinking so that steel companies can contribute to solving new types of problems while taking advantage of their abundant experiences.

Third, as a result of analyzing exterior remodeling project, it was confirmed that the original solution was embodied as logical ideas based on analytical thinking and creative ideas based on intuitive thinking were replaced, combined, and changed.

Fourth, it was confirmed that mutual communication through rapid prototyping is effective due to the nature of architectural projects with a limited time and cost.

Fifth, through quantifying carbon emissions, it was demonstrated and suggested that steel products have clear environmental advantages over aluminum products as a carbon handprint perspective.

List of Citation

Brown, T. 2009. Change by Design. Gimm-young Publishers, Inc.

Herb. B. 2018. The Good, The Bad, And The Wicked: Thinking About Design Thinking. FORM3. https://form3.com/thinking-about-design-thinking/.

Kang, M. & Lee, S. 2014. Abduction of Design Thinking: Theory and Practice of Creative Ideation. Semiotic Inquiry, 38(0), 7-35.

KBCSD(Korea Business Council for Sustainable Development). 2021. Calculation and Reporting Guideline of Societal GHG Reduction for Korean Steel Industry.

Kim, B. 2017. Lotte Advanced Materials Uiwang Business Center Adds Design to Its Chemical Business. The Bell. http://www.thebell.co.kr/ free/content/ArticleView.asp?key= 201709280100048460002908&svccode=00&page=1 &sort=thebell_check_time.

Kim, D. 2010. Introduction to Dongdaemun Design Plaza & Park. Magazine and Journal of Korean Society of Steel Construction, 22(6), 37-40.

Kim, M. 2016. Iron, add design. POSCO's Colorful Innovation. MK. https://mk.co.kr/news/business/view/2016/08/589732/.

Kim, S. 2015. Review of Freeform Buildings using the Digital Fabrication. Journal of Korea Institute of Building Construction, 15(2), 175-176.

Martin, R. 2009. The Design of Business. Woongjin Wings.

Moon, E. 2020. A Study on Design Thinking Class Model for Human-Centered Social Problem Solving - focused on ‘COVID-19 project’ using IDEO design thinking process -. Journal of Korea Society of Basic Design & Art, 21(5), 111-122.

Mootee, I. 2019. Design Thinking for Strategic Innovation: What They Can’t Teach You at Business or Design School. UX Review.

Rikke, F. D. 2022. The 5 Stages in the Design Thinking Process.https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process.
You, J. 2018. A Study on the Strategy and Design Characteristic of Planar Reconstruction in Digital Fabrication. Journal of Korea Society of Basic Design & Art, 19(2), 315-328.