CLASSIFICATION OF TRANSFORMABLE PRODUCTS BASED ON CHANGES IN PRODUCT FORM AND FUNCTION

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ABSTRACT

The sentence "form follows function" is the best expression of the relationship between form and function of a product in modern product design. This implies that the form is essential to implement the function while it should be optimized and minimized for the function. Unlike general products, transformable products are designed with the intention to change the function and form of the product according to the situation. This paper presents the types and characteristics of transformable products determined by Phase Model we introduced. We collected 147 transformable product cases and analyzed them according to the change of functions and forms in each product. As a result, we classified the transformable products into four types: partial transformable product, multi-form product, multi-function product and full transformable product. We found that each type has unique characteristics with potential to drive innovation in product design field.

Keywords: Design theory, Industrial design, Design engineering

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1 INTRODUCTION

Product design is a collaborative work between industrial designers who deal with form and use and engineering designers who tackle function and structure (Eder, 2013; Eppinger and Ulrich, 2015; Horvath, 2004; Kim and Lee, 2016). According to the "form follows function" style of architecture, though a form must follow the proposed function in a product design (Townsend et al., 2011). In contrast to more primitive styles, this style is minimalistic in appearance but consistently interrelated with the logical flow and function of the spaces to be enclosed into the design of a particular product. Similarly, the minimalist style, which prioritizes functionality and minimizes its form to the degree required for functionality, has received a significant impact on modern industrial design (Zhang, 2019; Liu, 2018). In this context, the form of a product is considered a design element that must be minimized in modern industrial design. However, 'minimizing unnecessary forms for the function of the product' ironically shows that the physical form of the product is essential to implement the function of the product. Most traditional products retain a fixed form optimized for a specific function. On the contrary, a transformable product consists of multiple forms for different functions with its usage scenario. It seems that transformable product design is barely understood in the current product design literature due to its complex mechanism in form and function consensus. Based on this notion, we investigated and classified the current transformable products to recognize transformable product design and explored its unique features.

1.1 Single form-function products

Most products comprise a singular form because their primary function is generally fixed, which defined the form. In fixed-form products, the form is intimately linked to the use of the function. For example, a spoon is one of the most classic examples developed in various styles in various cultures but most of the spoons have common form factors (a broad and concave head and a long stick-like handle) for the functions of holding and carrying food. Similarly, a smartphone is a cutting-edge complex product developed based on the physical functions of mechanical and electronic parts to fulfil user convenience related to grip, touch, view, navigation, positioning, and charging. Most of the current smartphones comprise a flat and rectangular form optimized to utilize functions. The form of most fixed-form products has evolved to optimize its function's use. It can be asserted that most modern consumer products come with a particular form that supports a single primary and fixed function. Products with moving parts, such as a gasoline engine consist of rotational parts, but their rotations cannot change the form of the product. It is subtle to state that the rotations of the wheels in a car or a bicycle, pressing keys on a keyboard, and pressing a power button on a TV, all of which transform the form of the product. Similarly, a person's appearance does not change even if he or she produces various facial expressions. As follows, products with moving parts working for the primary function possess a single form.

1.2 Two or more form-functions in a single product

Some products encompass multiple functions that can be used appropriately depending on their usage scenario. Although the form also follows the function and their form can be fixed or interchangeable. Figure 1a shows an example of a multi-functional product with a single form as two functions are applied to a fixed-form product. This product can be considered as a deformed design in which the form elements required for each function (gun and sword), which adversely influence both functions. Mixing a pistol and sword in one body could cause problems with the weapon's centre of gravity, and its reliability and durability. Furthermore, the barrel could interfere with the blade's function, or the trigger could interfere with the use of the sword. An example of a multi-functional product with a changeable form is illustrated in Figure 2b. The multi-tool can be appropriately used by transforming its form and functions depending on the situation as it is transformed into scissors or a knife, or it folds for carrying function. Although the performance of single functions has been sacrificed to some extent. This product represents a magnificent design that allows users to certainly carry a variety of functions on one object.

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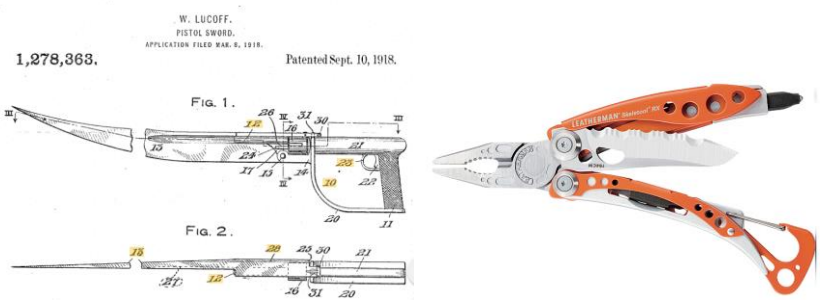

Figure 1. (a) pistol-sword (Lucoff, 1918), (b) Leatherman Skeletool RX (Leatherman Tool Group, 2017)

In recent years, there have been frequent introductions to transformable products because of the development of technology and the expansion of grassroots imagination. In the field of mechanical design, Singh et al. (2009) defined transformation as changing the physical state of a product to change or improve its functionalities. However, research on the design of transformable products has not received much attention in the design literature. Although research on shape change interaction (Follmer et al., 2013), the use of robot motion in the robot field (Nakata et al., 1998, Häring et al., 2011), and research for use in the architecture field (Liapi, 2001) deal with the transformation of the form. It seems that the current development is far from exploring transformable design that performs multiple functions through the transformation. To achieve improvements in product design through transformable design, research is needed to explore product design with multiple functions through the transformation. We explored the composition and interrelationship of the function and form elements to support the functions based on transformable design. We introduced the classification of transformable products based on their unique features from a single-form product.

1.3 The phase model for analyzing transformable products

A single-form product exercises a fixed function, however, a transformable product retains two or more phases in a usage scenario. In this manner, we proposed the phase model to explore the different features of transformable products. In each phase, the product retains its form and function, wherein the form exists as a physical state to implement the function. Figure 2 shows a diagrammatic presentation of the phase model with two phases, namely, phase A and B. These phases exclusively have their forms and functions with different state transformation. Each functional element is associated with a shape element. Besides, each function and shape element can be transformed when moving to a different phase. The phase model was used to analyze transformable products.

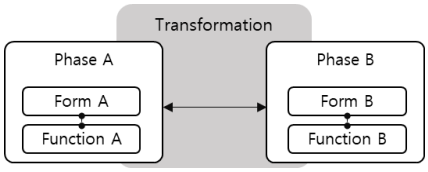

Figure 2. Phase model for transformable products

2 RESEARCH APPROACH

A transformable product is defined as a product that can change both functions and forms according to a usage scenario through the intended transformation. We collected the transformable product design cases according to the definition of transformable products. Each of these cases was then classified as a type of transformable products with the degree to which functions and form changed during the transformation process. Through this process, we examined the characteristics of the classified categories.

2.1 Collection of transformable product Cases

To collect transformable product cases, we requested the research participants involved in this study to select products that fit into the definition of transformable products. These products were among the winners of the Red Dot and IDSA design awards from 2014 to 2018. In this process, single form

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products with moving parts, such as an engine or a clock, was excluded. By investigating the award-winning product design cases, we expected to observe 1) well-designed products recognized by an authorized organization or group in the design field, and 2) not only traditional products but also concept products. Upon the completion of the case collection procedure, participants were invited to determine the final selection by considering whether the collected products were appropriate to be categorized transformable products.

2.2 Analyzing the phase model and classification of transformable products

Through several workshops, the participants applied the phase model to each case and classified the products based on how the form and function of each product change when moving from one phase to the other phase of the transformation.

2.3 Research participants

To collect and analyze transformable product design cases, participants should possess sufficient knowledge to understand the form and function of a product. Generally, students majoring in industrial design know the form and function of the product while students with engineering design majors understand the structure and physical functions of the product. Based on this, we selected four master's students as the research participants (male = 3, female = 1; age range = 25 to 30 years) who completed the combined curriculum of industrial design and engineering design and familiar with a product design practice. During the course of this study, each participant selected transformable product design cases individually and evaluated whether each case was appropriate as a transformable product. This activity was accomplished through a group discussion on the product design cases to ensure validity.

3 CLASSIFICATION OF TRNASFORMABLE PRODUCTS

The final selection process yielded a collection of 147 transformable product cases out of 2800 Red Dot and IDEA award-winning products. These cases were classified into four types of transformable products depending on the degree of change in function and form. The following sections present the types of transformation products.

3.1 Types of transformable products

There are four types of transformable products based on function and form change. As shown in Figure 3, the horizontal direction indicates the level of form change. On this axis, the form change of the product is classified into 'partial form change' and 'dominant form change'. The vertical direction indicates the level of function change. On this axis, the functional change of the product is classified into 'primary function change' and 'secondary function change'. Therefore, transformable products can be classified into function change-based transformable products (See red boxes in Figure 3) and form change-based transformable products (See blue boxes in Figure 3) according to each axis. The types of transformable products classified based on these two axes were 1) partial transformable products (45 cases), 2) multi-form products (91 cases), 3) multi-functional products (1 case), and 4) full transformable products (10 cases). Interestingly, multi-form products accounted for the most transformable products with 64.5% of the total, and only one case was reported for multi-function products. The characteristics of each case are described in sections 3.2 and 4.1. The features of function change-based transformable products and form change-based transformable products are presented below in Figure 3.

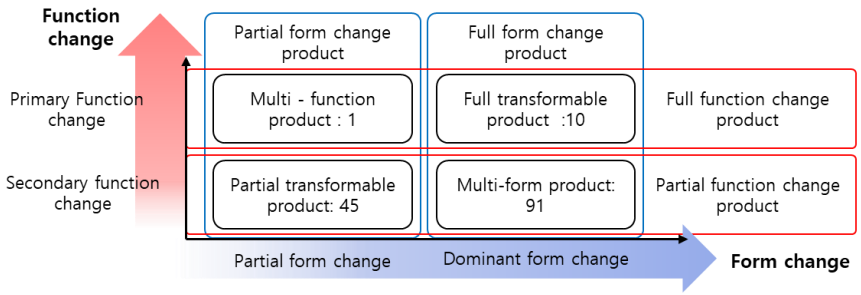

Figure 3. Classification of transformable product

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3.1.1 Function change-based transformable products

Miles (2015) categorized the product's function into a primary function for carrying out the original purpose and a secondary function to support the function. Function change-based transformable products can be largely classified into 1) full function change transformable products where primary functions change, and 2) partial function change transformable products in which secondary functions change (See Figure 4). The primary function change leads to a radical transformation that completely changes the role of the product before and after the transformation. The secondary function change represents a moderate transformation in which only partial functions are changed. Though the primary function of the product is maintained before and after the transformation.

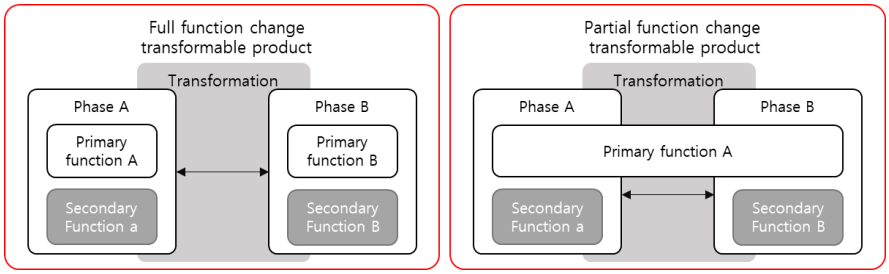

Figure 4. Diagrammed representation of function change-based transformable products

As shown in Figure 5a, the Ta-da chair is an example of the primary function change. The function is completely transformed from a cane to a chair. In Foldable Pot Trivet (Flip), as depicted in Figure 5b, the primary function as a trivet is retained, but its secondary function to support this primary function is enabled/disabled through the transformation. The Aep-200 endoscope represents another example of a secondary function change in which a secondary function (sub-display) is activated and deactivated while maintaining the primary function (See Figure 5c).

Figure 5. (a) Ta-da chair (Chih-Ting & Kuo-Lung, 2016), (b) Flip (Schneck, 2017), and (c) Aep-200 (Qiubo, Songting, & Xiaomin, 2016)

3.1.2 Form change-based Transformable Products

Greet (2002) introduced Rowena Reed Kostellow's form classification. This work suggested a hypothetical composition consisting of dominant, subdominant, and subordinate volume. At this place, the dominant volume is the largest, eye-catching, most spectacular element, and the element that dominates the entire form. The subdominant volume assists the dominant volume, and the subordinate is not as independent as the dominant or subdominant. Though it makes the design interesting and represents a separate design element that fills the gaps. We classified the transformable products into full form transformable products and partial form change transformable products. In the full form, the dominant form and structure are changed. Only some structural elements change in partial form change transformable products while maintaining the dominant form of the product (See Figure 6).

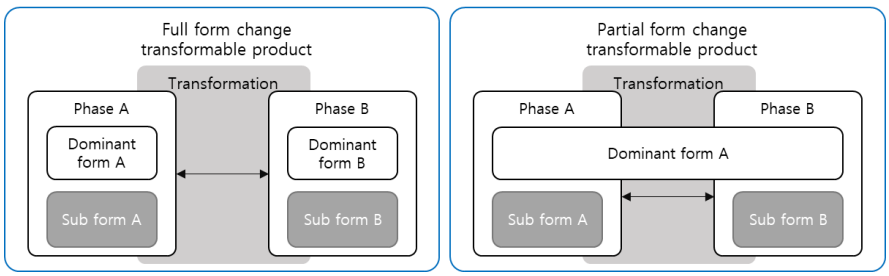

Figure 6. Diagrammed representation of form change-based transformable products

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Figure 7a is an example of full form change transformable products, which represent a product that can be transformed from a square bar to a keyboard or a keyboard to a square bar. There is no primary function change between the two phases occurs. The square bar state is intended for portability. Figure 7b is an example of a partial form change transformable product. The sub-form that plays the alarm function can be transformed while the main body that acts as an electronic clock is maintained.

Figure 7. (a) LG Rolly Keyboard (Park & Yoo, 2016) and (b) InOut (Serrano, 2016)

3.2 Features of the four types of transformable products

3.2.1 Partial transformable products

As shown in the phase model in Figure 8a, the primary function and dominant form of partial transformable products cannot be changed. The primary function A and form A (dominant form) cannot be changed and only the secondary function of each distinct phase and sub-form elements are required for its change. In Figure 8b, although the primary function is activated/deactivated through the transformation, which cannot be changed. The secondary function (side protection) to properly complete the primary function and the necessary sub-form (side guard) can be changed. In Figure 8c, the product can be transformed into a completed phase with a secondary function (auxiliary chair for children) while properly maintaining the primary function of the swing with the dominant form.

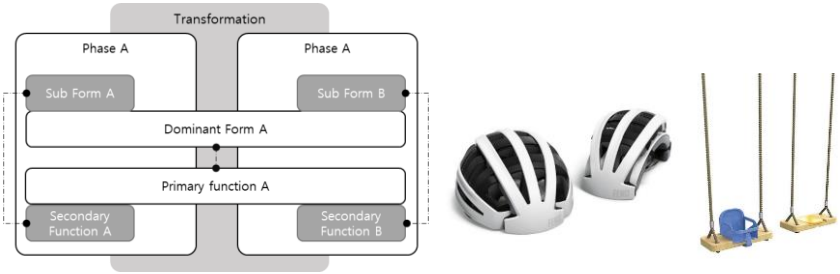

Figure 8. (a) Phase model for partial transformable products, (b) FEND One (Heifner, 2018), and (c) Dual Swing (Haimo & Song, 2016)

3.2.2 Multi-form products

In a multi-form product, the form changes radically while maintaining its primary function (See Figure 9a). Most products are transformed to substantially reduce the volume of the product for portability and storage purposes. Products classified in this group supported a volume-reducing transformation for carrying and storing the product. In Figure 9b, the primary function of the product (laptop) be unchanged, but the secondary functions, such as display, keyboard and touchpad can be changed. Through this kind of transformation, the dominant form of each phase can be changed. However, the form elements that make up the dominant form can still be connected to the primary function and secondary function even in the closed state of the product.

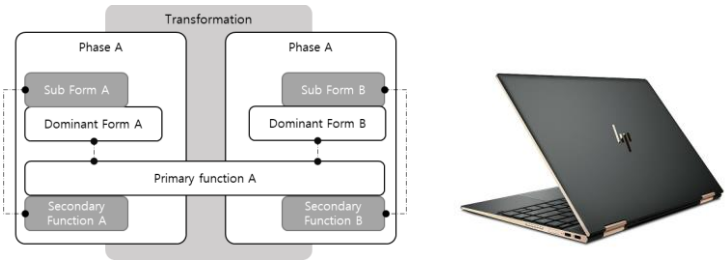

Figure 9. (a) Phase model for multi-form products and (b) HP Spectre x360 15 (HP Design & NativeDesign, 2016)

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3.2.3 Multi-function products

A multi-function product represents a full function change transformable product in which the dominant form is properly maintained while only the sub-form of the product is changed (See Figure 10a). Multi-functionality is viable in products in case the form elements required for the primary function of each phase are substantially matched. The product can be transformed from a chair to a seesaw (See Figure 10b). In this specific case, only the transformation of the sub-form is required and the dominant form produced by the central support and the large plate that existed in both phases.

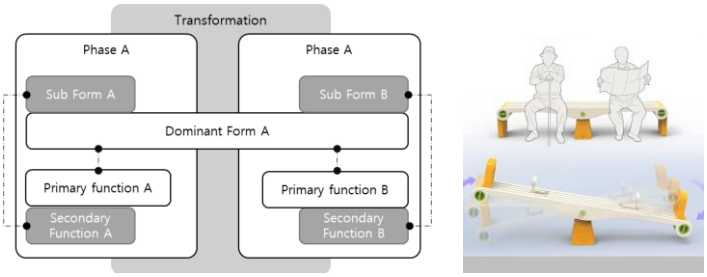

Figure 10. (a) Phase model for multi-function product and (b) Funny chair (Sun, He, Xi, Wang, & Bao, 2018)

3.2.4 Full transformable products

A full transformable product can completely change the primary function and the dominant form (See Figure 11a). Unlike the multi-function products, the dominant form required for the primary function of each phase is completely distinct. Therefore, the dominant form must be completely transformed. As depicted in Figure 11b, the Gami product is a cutting board and a knife sheath. In case, if the cutting board function is not in practical use, it works as a knife sheath (primary function A), and if necessary, it can be uncovered and used as a cutting board (primary function B).

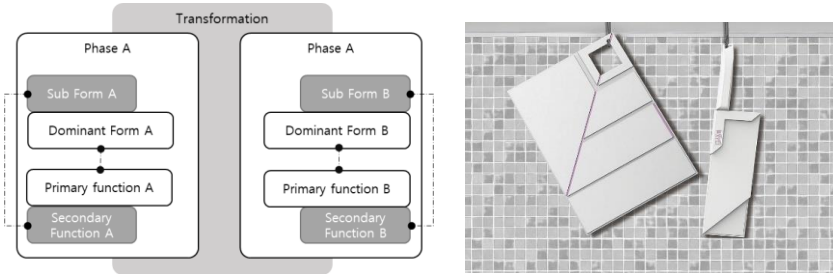

Figure 11. (a) Phase model for full transformable product and (b) Gami (Choi, Kim, Kim, U, & Washam, 2018)

4 INSIGHTS FROM THE CLASSIFICATION

4.1 Characteristics of design cases for each type of classification

We found that most transformable products were partially transformable or multi-form. Only 11 products were determined to have primary function change. In particular, 91 products were classified as multi-form, which were more than half of the cases (total = 147). Furthermore, several cases could be considered a similar product with the same primary function. Among the multi-form products, electric scooters (total = 9), strollers (total = 13), laptop (total = 20), tent (total = 7), and chair (total = 8) cases were found to be more than five times (grand total = 57). On the other hand, multi-function products or full transformable products were relatively uncommon. There were a few cases of multi-function products (total = 1) and full transformable products (total = 10). Based on the foregoing analysis, it is problematic to uncover commercialized cases because most of the existing cases were concept products. These types of products have no archetype, and none of them could be considered the same product group with the same primary function. Considering that the collected cases of transformable products in this study included concept products. It is apprehensive to even construct a user scenario of transformable products using multiple primary functions.

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4.2 The difficulty of transformable product design: interdependency between function and form elements

During the classification, we found some of the product cases were concept designs that were not commercialized. These products are expected to confront fundamental problems if realized due to lack of feasibility. In the Gami case (See Figure 11b), it is significant to keep the cutting board dry for cleanliness. However, the product is stored in a folded form, which may be detrimental to the dry condition of the product and expected to adversely affect its hygienic condition. In the case of Campike (Figure 12a), structural defects and an increase in considerable weight could constitute the main obstacles to the transformation mechanism. It is uncertain whether this product is more efficient than carrying a tent on a bicycle because the structural strength and weight of the travelling bicycle are vital. It represented a significant adverse effect on the functionality of a phase by the form elements required to implement the functions of another phase.

Figure 12. (a) Campike by Zixuan & Jiajia (2017) and (b) HP elite presenter mouse from HP Design Team (2018)

Fundamental design elements of a product design typically come up with interdependencies on each other (Evans, 1959; Pahl and Beitz, 2013). In the design process, it is essential to carefully consider the relationship between these design elements. From this point of view, the design of transformable products is immensely complicated than that of a single form product with one distinct phase. The forms and functions of a transformable product are required to be designed separately according to each phase. The forms of the two phases should also be physically connected through the transformation. To design an efficient transformable product, the functions of both distinct phases are vital to be properly utilized in the usage scenario. Moreover, the adverse effect on the product performance caused by the structural transformation should be minimized. From this point of view, Figure 12b can be reasonably considered as a prime example of a full transformable product. The function as a presenter in one phase and the function as a multimedia pointing device (mouse) in the other phase can properly be utilized in a usage scenario. In this manner, the transformation may not cause a significant adverse effect on each phase's product performance. We found many multi-form transformable products and fewer full-functional change products. In the case of multi-form products, all selected cases had a transformation in sufficiently reducing the space typically occupied by the product for carry-on or proper storage. The portable phase of these products may not require consideration for the usability of product functions because primary functions may be disabled. Designing these products could be considered easier than designing products with multiple primary functions. Partial transformable products with merely sub-form change in their secondary function can be considered easier to design than the primary function changes. For Multi-function products, the primary function changes, but the dominant form is properly maintained. In this case, the considerable difficulties typically required for structural design are reasonably thought to be relatively small. Of this sort, only one case was uncovered during the study. Considering this, it is formidable to uncover design cases where the form elements needed to implement the two or more diverse primary functions has been shared. For a successful transformable product design, it is universally required to minimize the adverse effect of each form element on the function of another phase.

5 DISCUSSION

5.1 The function of transformable products

The standard definition of function typically varies among academic researchers. Aurisicchio et al. (2011) divided the function into a technical function, aesthetic function, social function, and economic function. We considered only the technical function of the product without considering the aesthetic, emotional or social role of the product. Some products naturally possess transformations for purely

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aesthetic or emotional purpose. Based on this, we suggest further extended studies for these distinct types of transformations.

5.2 The relationship between technological advancements and transformable products

To efficiently implement the foldable phone without flexible display technology, the bezel must be properly attached in the middle. Although the form element (bezel) may harm the function of the foldable phone as a tablet PC with an open phase. The potential application of flexible display technology generously allowed developers to achieve the successful commercialization of foldable phones by overcoming the problem invariably caused by this form element. In the case of Camplike product, structural weaknesses and weight problems can be solved by developing novel materials. In Gami product, materials or technologies that can properly maintain dryness in a folded phase can overcome the problem associated with hygiene.

5.3 The function sharing in transformable product

Function sharing represents the process of simplifying product structure and improving product effectiveness by allowing a single structural element to perform multiple functions (Ulrich and Seering, 1988). A typical example of function sharing is a monocoque body that serves as both a frame and a body of an automobile or airplane. The multi-function product is the case where function sharing applies to a transformable product design. Both primary functions of the seesaw and the chair of the Funny chair (See Figure 10b) are properly implemented by the T-shaped form elements corresponding respectively to the dominant form. In the case of the multi-tool (See Figure 1b), the function sharing is achieved by implementing the handle functions commonly required for scissors and knives by a single form element. In this way, the design process that executes a function sharing in transformable products is considered to enable design improvement through minimizing unnecessary form elements of the product.

5.4 Phase model as a design tool

The phase model can be used as an effective tool to organize and map the function and form elements when designing transformable products. In Dual Swing (See Figure 8b), each distinct phase has a common primary function (swing) and a dominant form (a combination of strings and chairs) for implementation with different secondary functions for each phase and sub-forms for implementing them (Flat boards vs. Harnesses for child protection). These products correspond respectively to partial transformable products. It posits that design practice with the phase model can tentatively identify and organize functions and form elements. The use of the phase model can encourage designers to properly consider which form and function elements can be removed, assimilated and improved to more efficiently expresses the elements of each phase of the transformable product.

6 CONCLUSION

We classified transformable products and uncovered their unique features and characteristics. This study suggests the phase model as a framework for the analysis transformable mechanism. By following this model, we classified the changes in function and form into two stages (full-partial) respectively. Based on this, four transformable products could be classified: partial transformable product, multi-form product, multi-function product, and full transformable product. Each transformable product type indicated a difference in the degree of a transformation, design difficulty and transformation methods. This study suggests these factors are required to be addressed in detail in future transformable product design-related studies.

This study explored the distinctive characteristics of transformable product designs from a technical point of view. However, transformable products inevitably produce physical movements. Therefore, the transformation equally can be considered as an aesthetic, emotional element or as a means of interaction ability in a product design.

Recently, transformable products like foldable phones and rollable TVs, which can be called new product innovations, have been commercialized in the market. This development is majorly the result of the continuous development of innovative technology and flexible materials. Considering the

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current pace of technological advancements and incremental development in traditional products, further research on transformable product design is warranted.

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