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Expanded Phase Model for Transformable Design in Defining Its Usage Scenarios for Merits and Demerits

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Abstract

The product's transformation is considered for its fascination but it is not studied for its usage scenario. This study proposes an expanded phase model that can evaluate the usefulness of transformable products from the perspective of form, function and user scenario of a transformable product. We analyzed purpose of transformation, and identified user benefits from existing transformable products. This model allows designers/team to evaluate usefulness of transformable products by comparing user benefits of the product with appropriateness of form and function in a given usage scenario.

Keywords: industrial design, product design, design methods, transformable design, transformation1.

1. Introduction

In the American science fiction action film "Transformers: Bumblebee," released in 2018, a robot called Bumblebee transforms its shape into a car to run on a road. This transformation from a robot to a car has drawn considerable attention and attraction from viewers. Currently, more transformable products such as convertible furniture and foldable phone are being introduced. An example of a transformable product is a foldable bicycle (Sanders, 1987) whose forms and functions can be changed depending on the situation. As with the basic design principle in product design called "form follows function" by Sullivan (1922), it can be argued that different functions require different forms. According to the phase model proposed by Lee et al. (2021), a transformable product has two or more phases. Each phase consists of a form and a function and can switch to another phase with a different form and function through transformation. For example, a foldable bicycle has two phases. The form of a bicycle in one phase is suitable for driving functions. The folded form of other phases does not support the functionality of bicycle but is suitable for storage and portability. Likewise, good transformable products should secure the appropriateness of the function and form in each phase. Thus, we assumed that the usefulness of transformable products could be tested by evaluating the appropriateness of the forms and functions activated in each phase.

Singh et al. (2009) defined transformation in a product as the act of changing a particular state to enable a new function or improve the existing one. Gruhier et al. (2017) described a transformable product as a product that can adapt to various situations with multiple functionalities. Also, the transformation should be reversible. In this study, we define "a transformable product" as "a product that can change its functions and forms according to situations as intended in the design process." And we also defined a none-transformable product that does not meet the conditions as "a static product". For example, a foldable bicycle can be regarded as a transformable product. However, a watch with rotating handles is not a transformable product. Even though it has a rotating movement, there is no change in its function.

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Therefore, the typical watch can be regarded as static product. The function can be denoted as a verb-noun (Miles, 2015; Pahl and Beitz, 1996) that regards only technical functions that work in the real world (Crilly, 2010) and not in the emotional domain. Form refers to the physical structure of a product. We introduced an expanded phase model to test the usefulness of transformable products. This model helps us evaluate the appropriateness of forms and functions in each phase through the decomposition and comparison of forms and functions. We first investigated the user benefits of transformation products. Then, we applied the discovered user benefits from transformable products to test the usefulness of transformable products. The following sections describe how we identified user benefits, the expanded phase model, its applications, the discussion, and the conclusion.

Figure 1. Bumblebee (Robot / Car)

2. User benefits of transformable products

2.1. User benefits described in literature

In the review of previous studies on transformable products, "Collapsible" product (Mollerup, 2001) is a representative transformable product, which enables utilizing space-saving (Liapi, 2001; Oungrinis, 2006; Pellegrino, 2001)—the most common purpose of using transformation in products. Son and Shu (2012) also showed that spatial factors in products are an important merit to be exploited during the course of transformation. Kalyanasundaram and Lewis (2011) and Singh et al. (2007) emphasized that a transformable product can serve as various products through form reconfiguration. Weaver et al. (2010) indicated that the purpose of a transformable product lies in packaging, related processes, and common flow. Other design case studies, such as the study by Camburn et al. (2010), suggested four indicators for identifying whether a transformation is a viable solution branch to a particular design problem : share functions, adhere to a variable, accommodate a process, and store. Gruhier et al. (2017) argued that transformation provides various functions depending on the environment and context of use in which a product can adapt to the environment and reversibly transform. So, above studies show that 1) the functions necessary for the situation/environment can be used through product transformation, and 2) the form of the product can be transformed to facilitate its portability and storage.

2.2. User benefits discovered from existing designs

We collected designs of transformable products and analyzed the detailed user benefits that the designer attempted to achieve. We determined how user benefits could be explained based on changes in form and function. Four master's students (male = 3, female = 1; age range = 25 to 30 years) who completed the combined curriculum of industrial/engineering design and were familiar with product design practice participated in the collection of transformable products. They collected 147 qualified samples out of 2800 award-winning product designs from the 2014 to 2018 International Design Excellence Award and Reddot Design Award. These samples met the definition of the transformable product used in this study. Each sample included a description from which the purpose of the design could be determined.

2.2.1. Analysis of samples

Two PhD students in industrial design (two males; age range = 30 to 35 years) reviewed the samples and their descriptions. While analyzing and discussing the samples one by one, the purposes of transformation were extracted from each sample and refined as common words. As a result, five main transformation purposes were identified (Table 1). As shown in Table 2, each type of purpose was coded

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as a number (1~5). If one product had multiple purposes of transformation, it is coded as a combination of numbers. For example, a typical laptop can be coded as 345 because it can be transformed for storage and loading (3) / protecting the product (4) / portability (5). Subsequently, these two PhD students also analyzed and interpreted the merits of these purposes from the perspective of form and function change. From this, they drew out two major merits of the transformation: 1) usability from changing functions 2) utilization of space from changing forms (Table 1).

Table 1. Merits of transformation

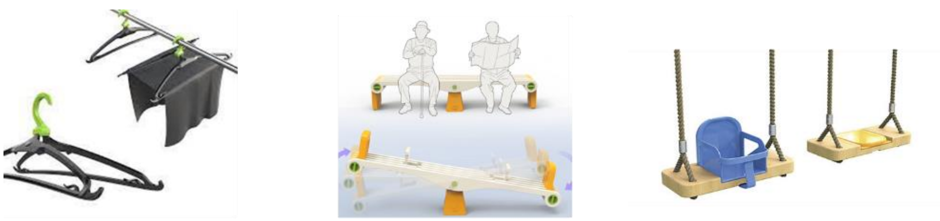
Purpose of transformation from sample analysis (code)	Merits of transformation in terms of form and function
Transformation for different users (1)	Merits of usability: change form to change function
Transformation for different function activation (2)	
Transformation for storage and loading (3)	Merits of space resource: change function to change form
Transformation for protecting the product / or a user from product (4)	
Transformation for portability (5)	

Table 2. The number of samples for each purpose of transformation

Purpose of transformation	1	2	3	23	34	35	235	245	345	2345	Sum
Number of samples	2	26	4	2	5	75	2	1	28	2	147

2.2.2. Merits of usability: change form to change function

In each scenario, different functions are required according to the characteristics (age, gender, location, etc.) of each user. Transformation can provide an appropriate form for each user. If a user needs a specific function depending on the usage environment or situation, the transformation can then provide the function required by the user in the corresponding situation. In some scenarios, the structure of product design can be transformed such that the user does not interfere with other actions if a particular function of the product is not in use. In transformable design, usability determined by the product's transformation should occur in a case where the product's functions are switching through transformation. Unlike transformable product design, static product design is relatively inconvenient because it cannot switch functions for multiple purposes owing to its static composition. Twin hanger (Jinlong, 2016), Funny chair (Sun et al., 2018), and dual swing (Haimo et al., 2016) are good examples of transformable product designs that change form to change function (Figure 3). static product cannot utilize various functions in this manner. Users must use two or more products to achieve multiple functions in such cases.



(a) (b) (c)

Figure 2. (a) Twin hanger (Jinlong, 2016) (b) Funny chair (Sun et al., 2018), (c) dual swing (Haimo et al., 2016)

2.2.3. Merits of Space resource: change function to change form

Transformation can be used to change the product's form for a space resource by minimizing the structural elements required for a particular function that is not in use. Thus, transformation is utilized to save space, facilitate portability and storage. It can also protect products from the environment and

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users. As shown in Figure 3, the HP Spectre x360 15 Laptop (HP Design & Native Design, 2016) and smart keyboard (Apple, 2016) can be a key example of a space resource transformation. When the display is closed, the volume of product decreases and portability increases. And the outer cover of the product protects the keyboard and display when the product is not used.

(a) (b)

Figure 3. (a) HP Spectre x360 15 (HP Design & Native Design, 2016) and (b) Smart keyboard (Apple, 2016)

From our sample, we found that the merits of usability and space resources determined by transformation are not mutually exclusive in a single product. For example, a multi-tool such as the Leatherman Skeletoll RX (Leatherman Tool Group, 2017) meets the usability requirement of transformation and increases portability by deactivating all functions to satisfy a space resource (Figure 4). Compared with the use of a typical Toolbox (BIKEINN, 2021), users who make use of the Leatherman Skeletoll RX can easily carry it with them and utilize various functions. As a result, user benefits from transformation can be explained as the merits of usability and space resources. In addition, these merits can be used as evaluation criteria for the usefulness of transformable products.

(a) (b)

Figure 4. (a) Leatherman-Skeletoll RX (Leatherman Tool Group, 2017) and (b) BIKEINN toolbox (BIKEINN, 2021),

3. Expanded phase model and its application

Based on the phase model proposed by Lee et al. (2021), we proposed an expanded phase model to evaluate the 1) usefulness of a transformable product and 2) appropriateness of its function and form.
In the phase model by Lee et al. (2021), the functions can be classified as 1) a primary function for carrying out the original purpose of product (ex: function of a bicycle is 'transferring driver') and 2) a secondary function to support the primary function (example: changing the direction (handle) / providing power (pedal)) (Miles, 2015; Pahl and Beitz, 1996). The form was classified as a dominant form (overall shape. ex: the overall physical structure of bicycle) and a sub form (partial shape. ex: the physical structure of handle for changing direction / physical structure of pedal for providing power) based on the idea of Greet (2002)—a hypothetical composition of dominant, subdominant, and subordinate volume. The functions of each phase were implemented according to the phase model. The primary function corresponds to a change in the dominant form, and a change in the secondary function is caused by a change in the sub form, which represents a partial structural element. Figure 5 shows the schematic of the expanded phase model. Each phase of the transformable product was placed in the usage scenario. A phase is defined by a primary function and dominant form. The primary function consists of a combination of secondary functions; the dominant form consists of a combination of sub forms. All secondary functions can be embodied in a sub form. For example, for a secondary function of a bicycle (changing the direction), a sub form (handle) is required.

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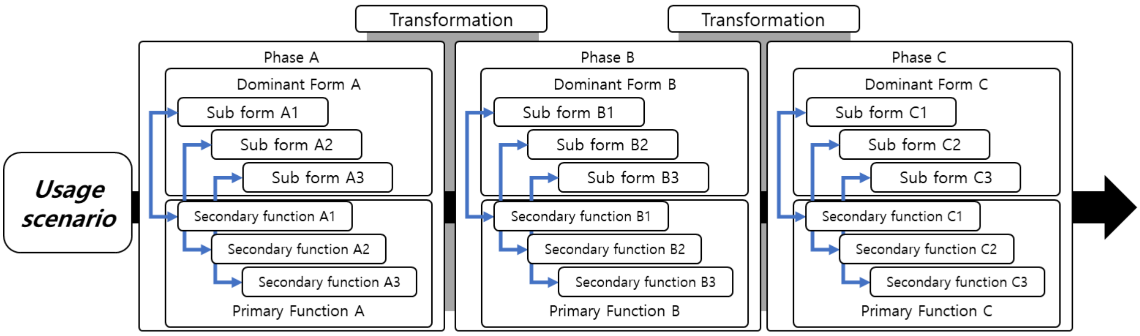

Figure 5. Schematic of the expanded phase model

3.1. Evaluating appropriateness of forms and functions in each phase

3.1.1. Effect of transformable structure on function

Form elements in a transformable product are not only required to achieve the intended primary and secondary functions of each phase, but also to perform the transformation between phases. This increases the complexity of the physical structure of a transformable product, which affects product performance. For example, a laptop computer has lower performance than a desktop computer. These complex structures can adversely affect their intended functions.

Therefore, it is crucial to evaluate the performance of the secondary functions that drive the primary function in a transformable product against a static product that provides the same primary function. It is necessary to observe the adverse effects of performance in one phase caused by the structural elements required for transformation and functions of the other phase.

3.1.2. Evaluating the performance of function of phases

Figure 6 shows the functions and forms of three products. HP Elite presenter mouse (HP Design Team, 2018) is a transformable product and has two phases (Phase A as a presenter and Phase B as a mouse). Phase A can be compared with 3M presenter (), and Phase B can be compared with Logitech M171 mouse (Logitech, 2016). The 3M presenter and the presenter mode (Phase A) of the HP Elite presenter mouse have the same primary function. Similarly, the Logitech M171 mouse and the mouse mode (Phase B) of the HP Elite presenter mouse also have the same primary function.

The performance of the corresponding secondary functions of these products were compared and evaluated. We marked "O" if performance of a function of the transformable product was almost equal to that of the static product and "△" if it was lower than that of the static product (see Figure 6). Each of the two phases has an activated primary function and dominant form. The primary function is divided into secondary functions and sub forms for implementing each of the secondary functions assembled to configure a dominant form. We coded SFnNA[number] for secondary functions and SForm NA[number] for sub forms for the 3M presenter(NA), as well as SFnA[number] for secondary functions and SForm A[number] for the presenter mode (Phase A) of the transformable product. SFnNB[number], SForm NB[number], SFnB[number], and SForm B[number] are all coded in the same manner for M171 mouse(NB) and mouse mod(B) of transformable product. Unlike the others, SFnAT/BT are functions required for a transformation. We evaluated all the secondary functions. In the presenter mode of the HP Elite presenter mouse, the form of the functional elements required for transformation did not significantly affect the performance of the secondary functions (SFnA1–4) as a presenter, which makes it similar to a typical presenter, thus marked them as " O.". However, considering the ergonomic form (SForm B1/B2), the mouse phase is unpleasant and has lower performance than a typical mouse. This means that SFnB1/B2 are more inconvenient than SFnNB1/NB2 while their performance degrades, thus marked them as "△." SFnB3 and SFnB4 functions implemented electronically may not present any major performance defects, which are marked "O." In some cases, it may be an "X" mark if the product is evaluated to be inconvenient for use at a serious level. Thus, we were able to compare the performance of the functions of a transformable product with that of a single-phase (static) product. Notably, the

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device required for SFnNB3 (transmit a signal) was not exposed as a form. Some electronic and mechanical devices that do not interact with the user may not be connected to the sub form.
By comparing with a static product, it is possible to show whether the form of the transformable product is appropriate for implementing the function or not and to determine which sub form element does not support the secondary function properly.

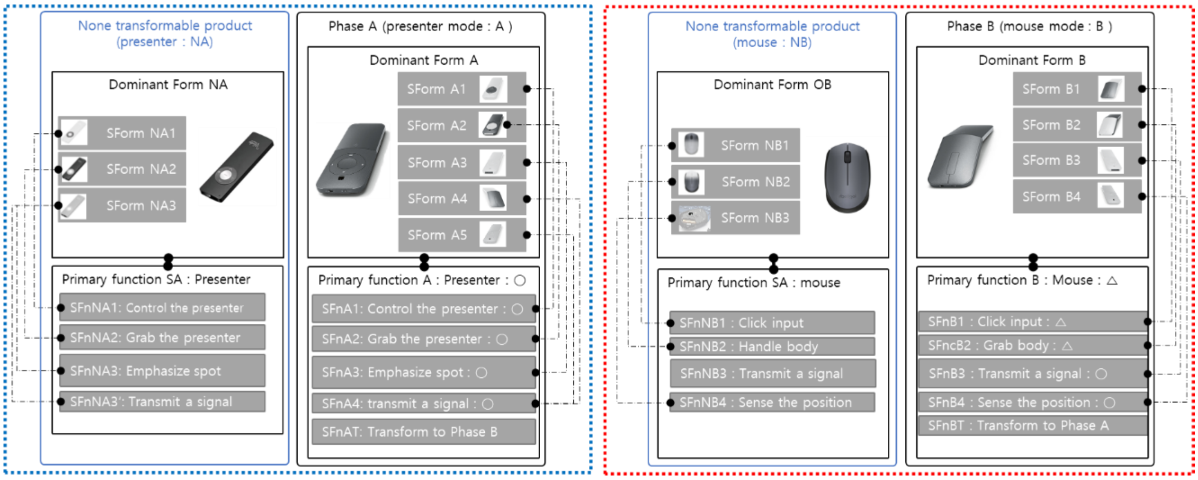

Figure 6. Performance evaluation of HP Elite presenter mouse (HP Design Team, 2018) with 3M presenter (3M, 2014) / M171 mouse (Logitech, 2016)

4. Evaluating the usefulness of transformable products

To evaluate whether the intention of the design is valid in a real usage scenario, Weaver et al. (2010) showed the purpose of transformable design as “related processes.” This implies that a transformable product does not simply provide a variety of functions, but also ensures that the functions should be properly connected in each usage scenario. First, the usage scenario is arranged as steps (Step A, B, C...), and the phases of the product used in each step are arranged along with the usage scenario steps. For each phase, the merits of usability and space resources can be applied. The type of merit varies according to product and usage scenarios. Figure 7 shows how the usefulness of the transformable product can be explained in a usage scenario. The use of a transformable product can be compared with the use of a static product(s). Compared to the use of static products, the merits of usability/space resource of transformable products in each phase can be described as positive (indicated by "+") / neutral (indicated by "=") in each circle, and in the rare cases, the merits may act negatively (indicated by "-").

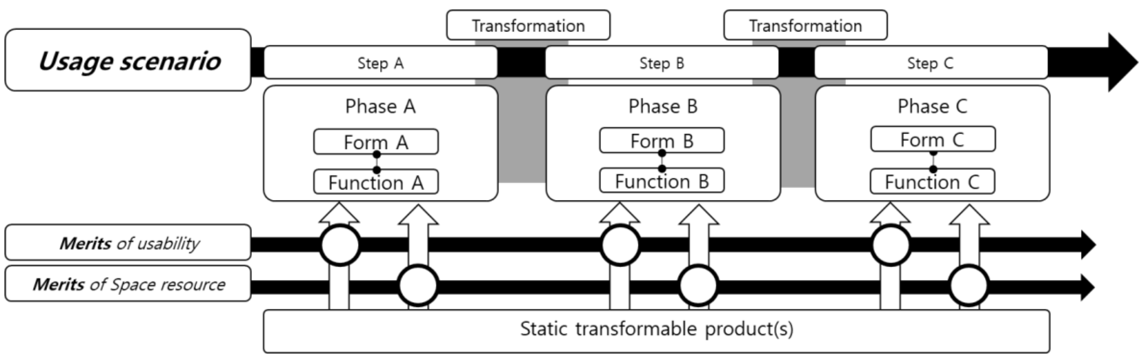

Figure 7. The usefulness of transformable products in the usage scenario

We explored how to use this model, with one product case representing the merits of usability and one product case representing the merits of space resources. Using this model, we evaluated the use and affordability of transformable products.

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4.1.1. A case of HP Elite presenter mouse: merits of space

We set a scenario in which a person uses an HP Elite presenter mouse in a conference room to evaluate usefulness of that product. The user brings the product to a conference, uses the presenter function (Phase A) to point to the presentation on the screen, switches to the mouse mode to control the computer (Phase B), and then changes it again to return after the conference (Phase A). In this scenario, the modes of use do not conflict and connect smoothly with each other through transformation. If the user uses a mouse and a presenter separately, they need more space and action steps. Thus, as shown in Figure 8, "Merits of Space resource" occurs in the mobile scenario as the product is easy to move and store. However, there is no better usability merit in this scenario because it achieves similar or slightly less functional performance compared to a normal mouse and presenter. In this scenario, although the functional performance of the mouse is slightly lower than that of the static product (Logitech M171), there is no serious issue with its use. Presentations do not require precise mouse control, such as in games, graphics, or CAD tasks, and this performance degradation is thought to be tolerable for users.

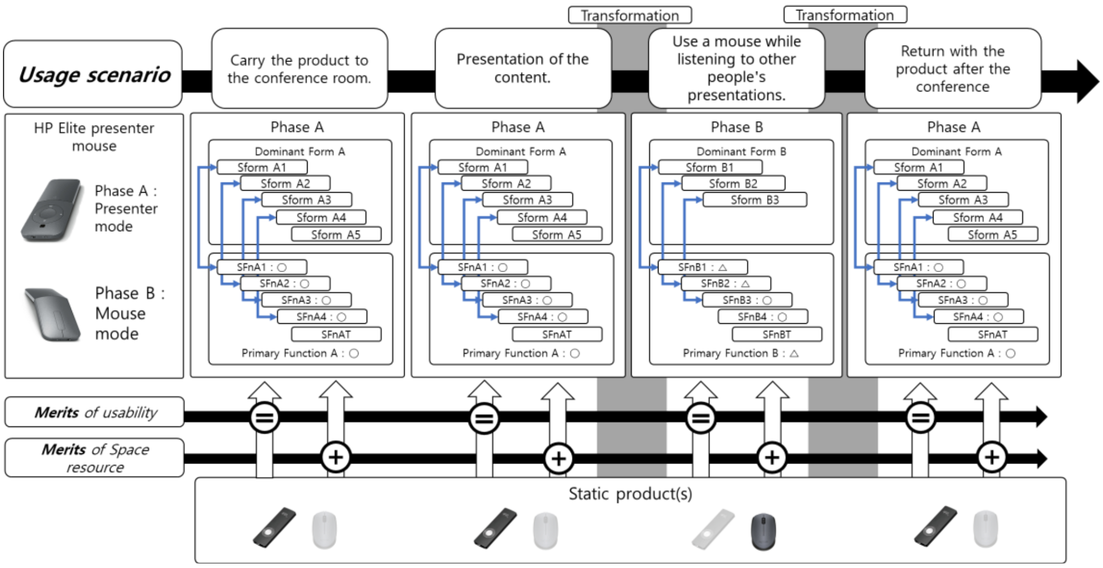

Figure 8. Usefulness of transformable product (HP Elite Presenter mouse (HP DesignTeam, 2018)): comparison with 3M presenter (3M, 2014) / M171 mouse (Logitech, 2016)

4.1.2. A case of Ta-Da chair: merits of usability

The Ta-Da chair (Figure 9) is an appealing product that can be transformed between a cane and chair. Figure 9 also shows the functional decomposition of the Ta-Da chair against the 30307 standard adjustable cane (Days, 2012) and swivel chair (Helinox, 2015). The secondary function of the cane that allows manipulation (SFnA1) was evaluated to be slightly uncomfortable. This is because the structure necessary for chair mode is expected to add weight and interfere with the center of gravity. In the chair mode, it was much more inconvenient than the swivel chairs because the seats were cramped and there was no backrest.

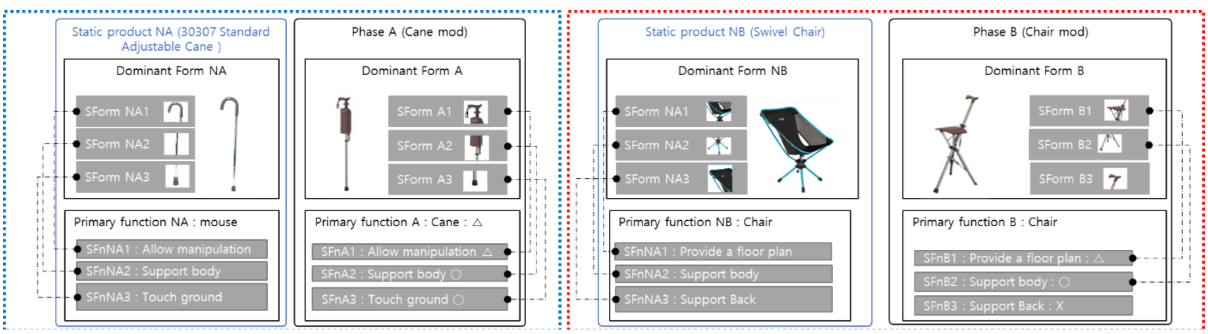

Figure 9. Performance evaluation of a Ta-da chair (Chih-Ting and Kuo-Lung, 2016) with a 30307 Standard Adjustable Cane (Days, 2012) and Swivel Chair (Helinox, 2015)

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To evaluate the usefulness of the Ta-Da, we constructed a usage scenario in which tourists move to the backwoods using the Ta-Da, sitting down at their destination, resting, and returning home (Figure 10). In this scenario, Ta-Da is compared to the 30307 standard adjustable canes. The benefit of the use of this product is the merit of usability. Although the performance of the chair is very low, it is possible to utilize the previously impossible functions of the chair. The usage scenario of carrying a chair and cane is unrealistic, and compared to the scenario of carrying only a cane, the merit of usability occurs in Phase B. If the weight of Ta-Da is not fatally heavy compared to a normal cane, this product will be useful. As such, usability enables functions that are difficult to use in static products or systems.

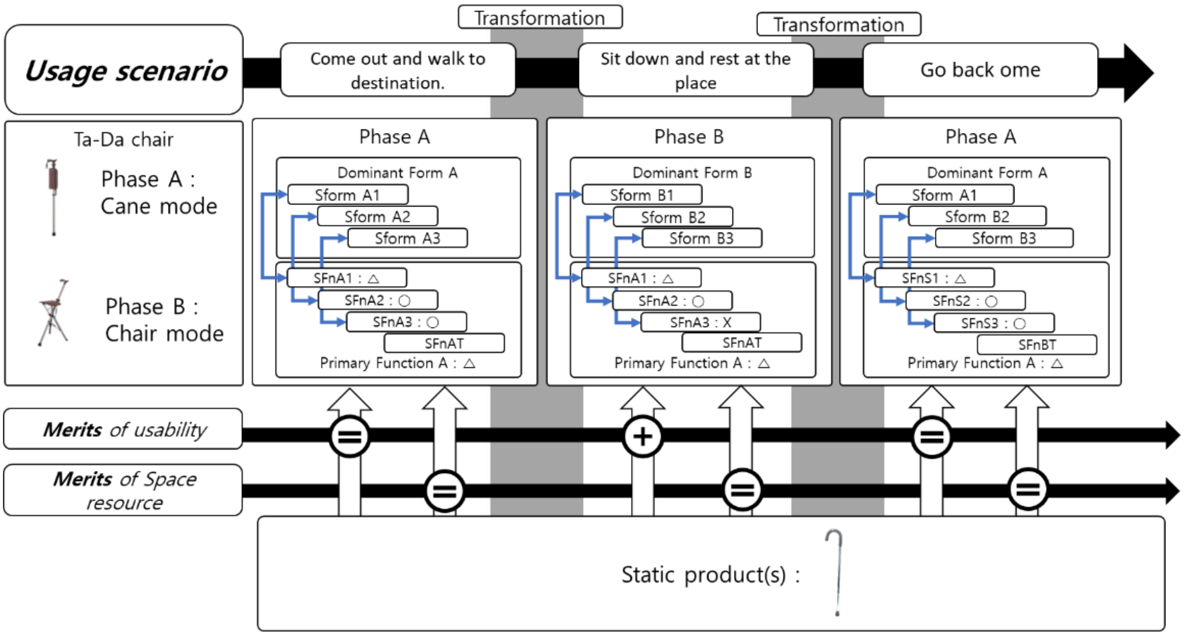

Figure 10. Usefulness of a Ta-da chair (Chih-Ting and Kuo-Lung, 2016) : comparison with 30307 Standard Adjustable Cane (Days, 2012)

However, even a slight twist in the scenario reduces this usefulness. For example, if the tourist moved to a bus terminal rather than to the backwoods, there would be enough places to sit, and there would be no reason to use the chair function of Ta-Da. In this case, the Ta-Da transformation is useless and only makes the product heavy. Therefore, it is necessary to consider whether the scenario for the product is appropriate and occurs often.

5. Discussion

Even though the sample products used in this study were designs that have received awards, many of them were yet to reach the actual product level. This finding suggests the importance of designing an ingenious transformable structure to implement a transformable product as well as identifying and evaluating an appropriate usage scenario. We believe that the proposed expanded phase model helps to evaluate the appropriateness of a usage scenario and the effectiveness of the functional performance of a transformable product. Most phases of transformable products can be compared with the functions and types of products that already exist. The HP elite presenter mouse or Ta-Da chair exemplified in this study is the same as the combination of the two products. However, if there is a phase with a completely different function and form from the existing product, the evaluation method needs to be determined.

Using the expanded phase model presented in this paper, the appropriateness of functions and forms in each phase and their usefulness in use situations can be evaluated. However, it seems that the form appropriateness for the function in each phase is often inferior to that of conventional static products. This means that the forms and functions of each phase of the transformable product are likely to conflict with each other. Therefore, from a user point of view, if the form appropriateness in each phase is somewhat inferior, the product will be beneficial only when the use in the situation can be compensated

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by the merits of transformation. Therefore, it can be said that the use of transformable products is quite dependent on the situation. This fact must be considered when designing a useful transformable product.

6. Conclusions

In this study, we propose an expanded phase model. This can be used to evaluate the usefulness of transformable products. First, this model can be used to evaluate the appropriateness of the form and function in all phases by decomposing the form and functions of each phase and comparing and evaluating the performance of the function with that of the existing product. Second, the usefulness of each phase (and product) can be evaluated according to the usage scenario. In conclusion, it is difficult to evaluate the utility of a transformable product simply by its performance and usage. Rather, it should be evaluated from the two perspectives suggested in this study. A transformable product can give the merit of space resources by activating merely the necessary functions and minimizing the structure that is not needed. If a transformable product is compared to a single static product, the merits of usability can be achieved because it can utilize multiple functions. In contrast, using static products in a scenario may benefit little from the merits of usability/space resource. This is the main reason for designing transformable products. However, the function of each phase in a transformable product has a high possibility of being inferior to that of a static product. This is natural because the simpler the product, the more advantageous it is to optimize its performance. We evaluated the functions by comparing the transformable product design samples with actual static products. This study explored the merits and demerits of transformable designs with specific usage scenarios by expanding the phase model of transformable designs.

Transformable design has attracted considerable attention because of the demand for multiple functions, materials, and space-saving properties in products. This study not only presents a model for evaluating a product but also explains the merits and demerits of transformable product design. This will help designers identify and evaluate an appropriate usage scenario when designing transformable products. Thus, this study provides a new perspective toward transformable design in which designers propose brilliant transformable ideas and evaluate the phase-dependent functions and scenario-dependent merits and demerits. Further research for exploring the important design elements in transformable designs may warrant the extension of the proposed model. Transformable product design is not a completely new design field, but there is a lack of research from an industrial design perspective. Thus, the present study is an effort to initiate further studies in this area.

References

3M (2014), *Wireless presenter JC-3000SB.* [online]. Available at: https://www.3mpointer.co.kr/goods/goods_list.php?cateCd=002 (accessed 15.10.2021).

Apple (2016), *Smart Keyboard.* [online] Red Dot. Available at: https://www.red-dot.org/project/smart-keyboard-9130 (accessed 11.11.2021).

BIKEINN (2021), *PRO Advanced ToolBox.* [online] Bikeinn. Available at: https://www.bikeinn.com/bike/pro-advanced-toolbox/137965041/p (accessed 11.10.2021).

Camburn, B.A., Guillemette, J., Crawford, R.H., Wood, K.L., Jensen, D.J. and Wood, J.J. (2010), "When to transform? Development of indicators for design context evaluation", *Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*--2010, *Montreal*, *Quebec*, *Canada*, American Society of Mechanical Engineers, New York, pp. 249-266. https://doi.org/10.1115/DETC2010-28951

Chih-Ting, P. and Kuo-Lung, W. (2016), *Ta-Da Chair.* [online] Industrial Designers Society of America. Available at: https://www.idsa.org/awards/idea/outdoor-garden/ta-da-chair [accessed 24.03.2021].

Crilly, N. (2010), "The roles that artefacts play: technical, social and aesthetic functions", *Design Studies*, Vol. 31 No.4, pp. 311-344. https://doi.org/10.1016/j.destud.2010.04.002

Days (2012), *30307 Standard Adjustable Cane.* [online]. Available at: https://www.amazon.com/Days-30307-Standard-Adjustable-Shape/dp/B07CKLN149 [accessed Feb 10].

GREET, G. (2002), *Elements of Design*, Princeton Architectural Press, New York.

Gruhier, E., Kromer, R., Demoly, F., Perry, N. and Gomes, S. (2017), "Transformable product formal definition with its implementation in CAD tools", *IFIP International Conference on Product Lifecycle Management*, *Grenoble*, *France*, *July 10-13*, 2027, Springer, Cham, pp. 212-222.

https://doi.org/10.1017/pds.2022.215 Published online by Cambridge University Press

Haimo, B., Song, Q., Hui, A., Junnan, D., Chunyan, H., Wei, L., Lei, M., Xiucheng, W., Kun, X. and Chenyuan, Z. (2016), *Dual Swing.* [online] Red Dot. Available at: https://www.red-dot.org/ko/project/dual-swing-26704 (accessed 16.05.2020).
Helinox (2015), *Swivel Chair.* [online] Red Dot. Available at: https://www.red-dot.org/project/swivel-chair-8085 [accessed 12.10.2020].
HP Design and NativeDesign (2016), *HP Spectre x360 15.* [online] Red Dot. Available at: https://www.red-dot.org/ko/project/hp-spectre-x360-15-46458 (accessed 16.05.2020).
HP Design Team (2018), *HP Elite Presenter Mouse.* [online] Red Dot. Available at: https://www.red-dot.org/ko/project/hp-elite-presenter-mouse-25351-25351 (accessed 16.05.2020).
Jinlong, Z. (2016), *Twins hanger.* [online] Red Dot. Available at: https://www.red-dot.org/project/twins-hanger-26391 (accessed May 15).
Kalyanasundaram, V. and Lewis, K. (2011), "A function based approach for product integration", *Proceedings of the ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 5: 37th Design Automation Conference, Parts A and B. Washington, DC, USA. August 28–31*, 2011, ASME, pp. 263-279. https://doi.org/10.1115/DETC2011-47922
Leatherman Tool Group, I. (2017), *Leatherman Skeletool RX.* [online] Red Dot. Available at: https://www.reddot.org/ko/project/leatherman-skeletool-rx-11096-11096 (accessed 16.05.2020).
Lee, H., Tufail, M. and Kim, K. (2021), "Classification of transformable products based on changes in product form and function", *Proceedings of the Design Society*, Cambridge University Press, pp. 641–650.
Liapi, K. (2001), "Transformable structures: design features and preliminary investigation", *Journal of architectural engineering*, Vol. 7 No. 1, pp. 13-17. https://doi.org/10.1061/(ASCE)1076-0431(2001)7:1(13)
Logitech (2016), *M171 wireless mouse.* [online] Logitech. Available at https://www.logitech.com/ko-kr/products/mice/m170-m171-wireless-mouse.910-004661.html (accessed 10.10.2021).
Miles, L.D. (2015), *Techniques of value analysis and engineering*, Lawrence D. Miles Value Foundation, Washington, DC.
Mollerup, P. (2001), *Collapsible: The genius of space-saving design*, Chronicle Books, San Francisco, CA.
Oungrinis, K. (2006), *Transformations: Paradigms for designing transformable spaces*, Harvard Graduate School of Design, Cambridge, MA.
Pahl, G. and Beitz, W. (1996), *Engineering Design: A Systematic Approach*, Springer, Berlin. https://doi.org/10.1007/978-1-4471-3581-4
Pellegrino S. (2001), "Deployable Structures in Engineering", In: Pellegrino S. (Eds.), *Deployable Structures*, Springer, Vienna, pp 1-35. https://doi.org/10.1007/978-3-7091-2584-7_1.
Singh, V., Skiles, S.M., Krager, J.E., Wood, K.L., Jensen, D. and Sierakowski, R. (2009), "Innovations in design through transformation: A fundamental study of transformation principles", *Journal of Mechanical Design*, Vol. 131 No 8, 081010. https://doi.org/10.1115/1.3125205
Singh, V., Walther, B., Krager, J., Putnam, N., Koraishy, B., Wood, K.L. and Jensen, D. (2007), "Design for transformation: Theory, method and application", 2007 *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Las Vegas, Nevada, USA*, September 4–7, 2007, ASME, pp. 447-459. https://doi.org/10.1115/DETC2007-34876
Son, J.J. and Shu, L. (2012), "Role of transformation principles in enabling environmentally significant behavior" In: Dornfeld D., Linke B. (eds), *Leveraging Technology for a Sustainable World*, Springer, Berlin, Heidelberg, pp. 563-568. https://doi.org/10.1007/978-3-642-29069-5_95
Sanders, M. (1987), *Strida 1.* [online] STRiDA. Available at: http://www.strida.com/en/company (accessed 25.05.2020).
Sullivan LH. (1922), The tall office building artistically considered, Lippincott's Magazine.
Sun, Y., He, J., Xi, H., Wang, J. and Bao, H. (2018), *Funny Chair.* [online] Industrial Designers Society of America. Available at: https://www.idsa.org/awards/idea/student-designs/funny-chair (accessed 11.10.2021)
Weaver, J., Wood, K., Crawford, R., and Jensen, D. (2010), "Transformation design theory: a meta-analogical framework", *Journal of Computing and Information Science in Engineering*, Vol. 10 No 3, 031012. https://doi.org/10.1115/1.3470028

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