Role of Transformation Principles in Enabling Environmentally Significant Behavior

Jay Jungik Son and L.H. Shu

Dept. of Mechanical and Industrial Engineering, University of Toronto, Canada

Abstract

We describe studies undertaken to better understand the relationship between mechanical transformation principles and environmentally significant behavior (ESB). Five existing transformable products were studied, and two new products were developed to address the limitations in one existing product. We applied lead-user methods to study those who undertake various tasks in environmentally preferable ways despite obstacles, as well as undertaking such tasks ourselves. We found that transformation increases the portability of products that support ESB and thus spontaneity in undertaking ESB. We conclude that transformable products do aid in overcoming obstacles to ESB that are not yet addressed by appropriate infrastructure.

Keywords:

Design for Environment; Environmentally significant behavior; Transformation principles

1 INTRODUCTION

Transformable products change either spatially, by collapsing/ expanding, or functionally, by exposing new surfaces and features depending on product configuration. We noted a potential relationship between environmentally significant behavior (ESB) (Stern, 2000) [1] and transformation principles (Singh et al., 2009) [2]. This paper aims to further understand and explore this relationship such that it can be better exploited to support ESB.

Lead users provided the context where we first noted a relationship between transformation principles and ESB. Lead users are those who often have needs ahead of the general population, and in many cases, have already developed their own solutions to these needs. Lead users in ESB include individuals who perform physically or logistically challenging tasks using environmentally preferred modes of mobility, e.g., transporting furniture on public transit.

This paper is organized as follows. Section 2 presents related work in ESB, transformation principles, and lead-user methods. Sections 3 and 4 describe how a potential relationship between ESB and transformation principles was first noted, and five existing transformable products we studied to better understand this relationship. Observed benefits and limitations are summarized in Section 5. Sections 6 and 7 describe two transformable products, newly developed to address some limitations identified in one existing transformable product, and additional insights gained. Finally, we conclude and summarize in Sections 8, 9 and 10.

2 BACKGROUND

2.1 Environmentally Significant Behavior (ESB)

Stern (2000) defines environmentally significant behavior by:

1. Its direct impact on the environment (e.g., forest clearing, household waste disposal), and
2. An individual's intent to change (benefit) the environment [1].

While the effect of individual environmental behavior is limited, "the aggregate of such behavior" can have significant positive effect [1].

Stern identifies four types of intervention for ESB: (1) religious and moral approaches, (2) education, (3) efforts to change the material incentive structure of behavior by providing monetary and other types of rewards or penalties, and (4) community management.

We propose another approach, that of identifying, and overcoming through product design, obstacles to ESB.

2.2 Transformation Principles

Singh et al. (2009) compiled a list of transformation principles and facilitators observed in consumer products, patents, and biological organisms [2]. The three transformation principles, or generalized directives to bring about a certain type of mechanical transformation, are 1) expand/collapse, 2) expose/cover, and 3) fuse/divide. These principles aim to 1) change occupied volume, 2) alter functionality by revealing or concealing a new surface, and 3) divide a product into many parts or combine multiple parts into one. Example products that use transformation principles include 1) umbrellas that extend and collapse canopies, 2) laptops that conceal and reveal screens and keyboards, and 3) screwdrivers with exchangeable bits to accommodate various screw heads. In addition, twenty transformation facilitators (e.g., flip, fold, material flexibility) enable various types of transformation when applied together but cannot create transformation when applied singly.

Singh et al.'s transformation principles comprise one aspect of adaptable product design [3], and focus on physical principles involved in transformation or reconfiguration of products.

2.3 Lead-User Methods

Lead users operate under extreme requirements, experiencing needs that ordinary users may not (e.g., casual jogger versus the marathon runner who developed the Powerbar™). Solutions developed for extraordinary situations often benefit ordinary situations (e.g., anti-lock braking systems used in automobiles were developed for planes landing on aircraft carriers) [4]. Extraordinary lead-user methods aim to turn ordinary users into extraordinary/lead users by placing them in extraordinary situations [5].

Applied to the mobility/transit aspect of ESB, extraordinary users include those with a range of disabilities, the elderly, and those tending to young children. However, university student bicyclists can also comprise a class of **situational** extraordinary users, as argued in one of the student projects summarized below. Extraordinary situations include commuting with physical loads and under adverse weather. Extraordinary users studied include those who bike regularly in the Canadian winter, a cyclist who brings his bike on business trips each involving multiple cities, and students who transport furniture without using motorized vehicles.

The lead-user method has proven to be effective for identifying ESB facilitators. Srivastava and Shu (2011) chose Mennonites as lead users due to their low consumption lifestyles, and found that resources in discrete units instead of continuous flow facilitated resource conservation [6]. We apply lead-user methods to discover new insights about transformation principles in relation to ESB.

2.4 Contrast with Other Design for Environment (DFE) Work

Much past work on product design for the environment (e.g., [7, 8]) focused on life-cycle aspects of products, e.g., recyclable materials, fuel efficiency, etc., to reduce negative effects on the environment. In contrast, we focus on consumer behavior, and how products can affect behavior to reduce environmental impact.

3 RESEARCH METHOD

3.1 Preliminary Observations

Our research was inspired by past student projects to design products that enable environmentally preferable behaviors. Three such projects [9, 10, 11] developed a flattening bike helmet, a compressible reusable coffee cup, and a baby stroller that can convert into a baby carrier, shown in Figure 1. Interestingly, all three projects concluded that incorporating a transformative mechanism addresses the main obstacles to the corresponding desired environmental behavior. Table 1 lists for the three projects, the lead users studied, obstacles to ESB identified, and concepts developed.

(a) Concept created (b) Prototype built

Figure 1: Stroller that is convertible into carrier.

	Flattening bike helmet	Compressible coffee cup	Convertible stroller
Lead user studied	Student bikers who must carry helmet from lecture to lecture	Undergraduate students who don't have a personal locker or desk at school	Baby stroller users who ride public transit as their main means of transportation
Obstacle to ESB identified	Bulkiness of the helmet, hassle of carrying	Bulkiness of the cup, hassle of carrying, leakage	Bulkiness and weight, spatial contraints in public transit
Suggested conceptual solution	A helmet that flattens when not in use	A cup that collapses into a disc when not in use	A stroller that converts into a front or back child carrier

Table 1: Student projects that related ESB and transformation.

3.2 First-Hand Use and Observational Data

The authors personally used transformable products to appreciate use contexts and possible user behaviors related to the products examined, rather than focusing on their technical aspects only.

We tested seven transformers to investigate the potential relationship between transformation principles and ESB. We obtained five commercially available transformable products that can enable various environmental behaviors (e.g., reducing use of disposable water bottles, cycling and using public transit instead of driving), and then developed prototypes for two new transformable product concepts.

Our use/test periods ranged from two weeks to six months. We continued to use the product tested as long as we continued to obtain new insights and observations. Testing and observing over a long period of time enabled us to encounter unexpected situations where the products were needed or became useful in a new way. We also tested the products in a wide range of situations and environments. For example, we used the collapsible reusable water bottle while working in an office environment, while walking around outdoors, and even while playing sports. Testing in a variety of situations helped us to find particular cases where the products failed to be useful or couldn't perform properly, and identify why such limitations occurred.

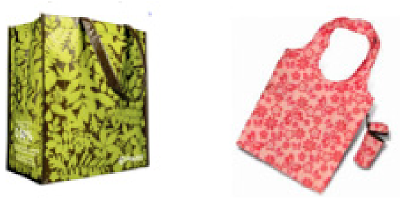
Limitations of our method include the often-significant time required to test each product. This requirement logistically limited the number of products that we could study. On the other hand, we were able to find very few transforming products that enable ESB. Another limitation is that having one or two main testers may bias our observations and interpretations. We addressed this limitation by identifying and interviewing actual users of the products, and recruiting other testers.

4 EXISTING TRANSFORMABLE PRODUCTS TESTED

Below we describe the five commercially available transformable products we studied to better understand the relationship between transformation and ESB.

4.1 Stowable Shopping Bag

Toronto recently required retailers to charge consumers for the use of disposable plastic bags, which led to the availability of a myriad of reusable shopping bags. Figure 2 shows two styles of commonly available shopping bags. We draw from our own experience to identify the strengths and weaknesses of each, and extrapolate to other shopping bags. While the bag on the left is more durable and can carry more, its bulkiness makes it less conducive to being personally carried except during planned shopping trips. The bag on the right, although less sturdy, collapses and packs tidily into its own attached pouch, and is more likely to be carried at all times and be available when needed. Extrapolating, while a wheeled shopping bag can enable one to carry even more, it is even less likely to be available except on planned shopping trips. We continue to use and test these products in our everyday lives.



(a) Durable but less collapsible (b) Collapsible but less durable

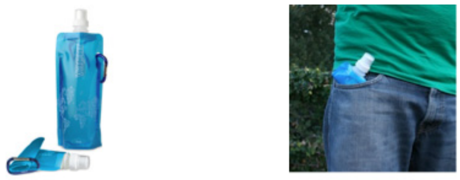
Figure 2: Commonly available reusable shopping bag styles.

4.2 Vapur Reusable Water Bottle

The Vapur Anti-Bottle is a reusable liquid container made of flexible polyethylene that allows it to be flattened and rolled or folded. We tested this product by using it regularly over about six months.

When flattened, this container can fit in spaces as small as pants' pockets, as shown in Figure 3b, and smaller compartments of bags. The container's ability to collapse made it conducive to being almost always carried in a bag without conscious planning, enabling its use instead of buying disposable bottles of water.

Observed limitations of the product included: difficulty of drinking from the container with one hand (only in the beginning), and the occasional inconvenience of having to find a suitable water source. In addition, collapsing or drinking from the container produced a cracking noise that may be bothersome in a quiet environment.



(a) Folded and unfolded states (b) Stored in pants' pocket

Figure 3: Vapur Anti-Bottle.

4.3 Dahon's Pango folding bike helmet

Dahon, a bicycle manufacturer, designed a folding helmet for cyclists, shown in Figure 4. The Pango helmet consists of an external plastic shell, and unlike the one-piece foam in most bike helmets, segmented foam plates that form the inner part of the Pango. The segmentation enables Pango's structural transformation, but may also prevent it from meeting U.S. safety standards. We used the helmet for two weeks.

One expected and confirmed benefit of the Pango was that foldability enabled its smaller size when not in use, and thus it could be stored in a bag without taking up as much space as regular helmets would. This benefit was especially salient when it was tested on BIXI, a shared bicycle system in cities including Toronto. That is, one may not have planned to use a bicycle but could still wear a helmet during an unplanned ride. However, the folded size, (9.5"x4"x6"), about 45% of the volume of a typical bike helmet, is not significantly smaller than a regular helmet.

In addition to the reduced protection, another limitation of the Pango is poor fit compared to regular helmets. The folding mechanism seems to constrain the dimensions and degrade the helmet's fit.

(a) Fully expanded (b) Folded for storage

Figure 4: Dahon's Pango folding helmet.

4.4 Magna Cart

The Magna Cart, shown in Figure 5, is a transformable hand truck. Features that involve transformation are a telescoping handle, retractable wheels and a hinged base plate. In contrast to how the product may be used by drivers who store it in their trunks, we tested the product as a personal hand truck for transporting bulky and/or heavy objects either while walking or using public transit.

Notable benefits included the Magna Cart's compact size compared to nontransforming trolleys, and overall durability. We used it for loads of up to 60 lbs, where all parts seemed to work very well except for the telescoping handle. We set 60 lbs as a limit because we assumed individuals are unlikely to transport objects heavier than this by public transit. We were also surprised that it worked fairly well on transporting objects up most stairs.

However, the Magna Cart had a few drawbacks. First, when folded, it was still somewhat bulky and heavy to carry on public transit and while walking. Since even in its folded state, it was too large to fit completely into most bags, one often had to carry it separately by hand. The second limitation, mentioned above, was that its telescoping handle permanently buckled from the transported load while being wheeled and lifted up stairs.

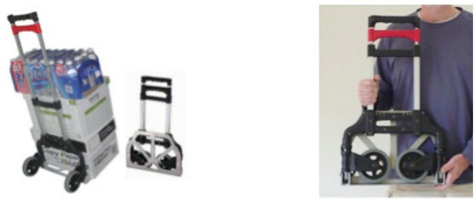


Figure 5: Magna Cart.

4.5 Strida Folding Bicycle

The Strida folding bicycle is one of many available folding bicycles. We chose to study this particular bike since one of its design requirements is that it can be carried onto public transit [12, 13]. Figure 6 shows its triangular main frame that can be folded into a compact, wheeled walking stick for storage and carrying.

Figure 6: Strida folding bike.

We noted many advantages of the bike during product testing. First, it was compatible with most dimensional constraints in public transit settings such as narrow turnstiles and streetcar entrances, as well as limited space in transit vehicles during rush hour. Second, it was relatively lightweight (26 lbs/12kg), and could be carried up or down stairs easily. Elevators and escalators were often unavailable even in subway stations, and significant flights of stairs were the only option. Folding and unfolding the bike only took about 5 seconds after one learned the mechanism. Finally, because it was conducive to being carried indoors, there was less concern about bicycle theft, which occurs commonly in Toronto.

However, the absence of gears in the particular model tested led to observed limitations. While the extra work required to ride uphill compared to a geared bicycle is not often encountered in relatively flat cities like Toronto, it may limit usability in hilly cities such as San Francisco. Also, the slower speed achievable compared to regular bikes made it awkward to ride on roads or bike lanes. Surprisingly however, the bike was easier to balance and maneuver at slow speeds (e.g., on sidewalks) compared to regular bikes.

In addition to first-hand use, we also interviewed six owners of the Strida bike to collect more usage insights. Based on the interviews, the most popular features of the bike included: not having to worry about theft, saving storage space, and being able to use multiple means of mobility in one or multiple cities. Some users also mentioned that they became less sensitive to bad weather because they can simply take the bike into a taxi or public transit in response to heavy rain or snow mid-trip.

5 CONCLUSIONS ON EXISTING TRANSFORMERS

5.1 Portability

As expected, the transformable products studied confirm that portability is enhanced by the expand/collapse transformation principle. By enhancing portability, one can:

1) Reduce solid waste generated by carrying reusable products, e.g., shopping bags, coffee cups and water bottles, instead of using disposable products,

2) Better engage in environmentally preferred activities, e.g., riding a bicycle more safely with an easier-to-carry helmet, and more flexibly, without worrying about theft, by using a folding bicycle.

In the five products studied, the expand/collapse principle was enabled by the use of flexible material, telescoping parts, folding parts, and retractable plates. Singh et al. had listed some of these strategies as transformation facilitators [2].

5.2 Spontaneity

While portability was an expected benefit, less expected was that, portability enables spontaneity. For example, the more compact the collapsible shopping bag, the more likely it will be carried at all times, making it possible to support spontaneous use. Similarly, a folding helmet allows one to make safer, spontaneous use of BIXI rental bicycles, rather than taking a cab when the need for such a trip arises unexpectedly. Finally, users of the Strida bicycle know they can easily take the folding bicycle on transit in case of inclement weather, rather than not taking the chance of riding in bad weather.

However, spontaneity also requires availability of appropriate infrastructure. For the Vapur water bottle, one needs a suitable source of water before one can use the bottle spontaneously. BIXI rental bikes must also be available where needed for one to be able to bicycle spontaneously rather than take a cab.

In contrast to the collapsible grocery bag, water bottle, helmet, and bicycle, the Magna Cart was not sufficiently portable to make spontaneous use of it likely; therefore, we developed two transformable products, to address the same need, with improved portability to enhance spontaneity. While the Magna cart used the expand/collapse principle, we applied the other two transformation principles, namely fuse/divide and expose/cover.

6 NEWLY DEVELOPED TRANSFORMERS TO ENABLE ESB

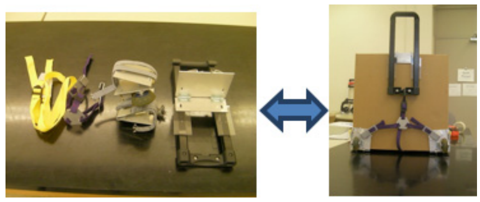
Two new transformable products were developed to address the limitation observed for the Magna Cart, i.e., it was not sufficiently portable to enable its target ESB in a spontaneous manner.

6.1 Trolley with Dividable Modules (Prototype)

We developed a trolley with dividable modules for two objectives: 1) to increase its portability, and 2) to apply and better understand the fuse/divide principle. We identified and prototyped a product concept, the Move-it cardboard cart developed by David Graham [14]. The product is designed for those who don't use personal automobiles to transport large boxes. The design consists of a handle and two wheels that adhere to corners of corrugated fiberboard boxes to facilitate transportation of the boxes [14].

In contrast to the original design, we decided to make our prototype more durable by using metal for the corner parts and a retractable handle system extracted from a wheeled suitcase. Also, we incorporated adjustable straps rather than the adhesives in Graham's original idea to attach the cargo to the cart. We also designed foldable wheel modules for better storage and portability. All the parts of the prototype are shown in Figure 7a.

After prototyping and testing the cart, we noted three benefits and three limitations of the transformable product. The most noticeable and perhaps anticipated benefit was its small size when divided and folded; all the modules combined easily fit into a gallon (11" X 14") size Ziploc bag, and thus sufficient portability was achieved. Another, less anticipated benefit was the ease of balancing a large box because the wheels were always located at the corners of the box. The final benefit was that the cart, being dividable, accommodated a wide range of box sizes. On the other hand, limitations included a smaller load-carrying capacity (up to 50 lbs) and lack of durability compared to the Magna Cart. While these limitations may be reduced during prototype refinement, the third limitation, a more significant setup time, i.e., attaching the cart to the cargo, is likely a consequence of the separate parts.



(a) Modules separated (b) Modules attached onto box

Figure 7: Trolley with dividable modules.

6.2 An Object-Carrying Jacket for Cyclists (Prototype)

We next applied the expose/cover principle to explore its effect on creating a highly portable product that assists in transporting heavy or bulky objects. This product is intended to help bikers or public transit users move such objects. The product has two functional parts: a jacket and a back strap system. The jacket is similar to a sport rain jacket, while the back strap system has five tie-down straps arranged to allow secure attachment of objects of various sizes and shapes. When the carrying function is not needed, the back straps can be covered to maintain the look of a regular jacket. To carry an object, one unzips the cover to expose the straps and buckles as shown in Figure 8.

This product is intended to offer two unique benefits. First, the product can be used like a regular rain jacket when the carrying function is not needed, thereby achieving portability that enables spontaneity. Although the straps are hidden when not in use, the prototype jacket was still a little bulkier than a normal jacket, which may be an obstacle to some users. Second, the product enabled a new method to carry bulky and/or heavy objects that do not fit in backpacks while riding a bicycle. The prototype demonstrated an ability to carry up to at least 58 lbs.

However, we also found some major limitations that would likely be reduced by improving the prototype. For example, the range of bodily movement was restricted when carrying a large volume/weight. Also, too much of the load was uncomfortably supported by the shoulders and chest, affecting one's breathing when the jacket was zipped up. Figure 9 shows the jacket in use.

(a) Front view (b) Back, straps covered (c) Back, straps exposed

Figure 8. Object-carrying jacket for cyclists.

(a) Object attached (b) Use while walking (c) Use while biking

Figure 9: Object-carrying jacket for cyclists in use.

7 CONCLUSIONS ON NEWLY DEVELOPED TRANSFORMERS

Additional insights gained through the development and testing of the above two transformable products are as follows.

7.1 Facilitating Carrying / Transporting Beyond Collapsibility

Although the fuse/divide principle was applied to the dividable cart to improve portability, it also improved the stability of the object carried by placing the wheels at the corner of any box carried.

Division of modules can also separate an unmanageably heavy or large object into multiple pieces, each with manageable weights and sizes. The baby stroller in Section 3.1 was dividable into two modules (i.e., a baby carrier and a collapsible chassis). This separation of modules could overcome the obstacle of stairs by allowing users to carry two modules separately (by wearing one and holding the other). Otherwise, one must lift the stroller and child combined in an ergonomically compromised way when help from a second adult is unavailable. Of course, a child can also be removed from any collapsible stroller and the two can be separately carried up stairs. However, most strollers are not designed to facilitate this specific task, and the task of carrying everything up or down a flight of stairs is somewhat burdensome.

7.2 Adding ESB-Related Function to Commonly Used Products

Although the object-carrying jacket prototype requires further refinement, the idea of adding a new ESB-related feature to a commonly used product merits further exploration.

Figure 10 shows a backpack with a solar panel as an example of a product with an additional ESB-related feature. Since many people use a backpack or other bag daily, a solar panel can both reduce demand and improve convenience by having an alternative source of energy to power or recharge small electronic devices.

Figure 10: Voltaic Converter Solar Backpack [15].

8 RELATIONSHIP BETWEEN TRANSFORMATION AND ESB

8.1 Compromised Function

Despite the advantages of volume change enabled by the expand/collapse principle, collapsibility sometimes compromised important product qualities. For example, the Magna Cart's telescoping handle bent more easily than a handle on a nontransforming cart, and segmented foam plates of the Pango folding helmet reduced its protective capacity. In the Pango helmet's case, the functional compromise was so critical that the product could not be introduced into the North American market.

However, functional compromises caused by transformation are not always critical. In addition, the benefit achieved through transformation can be more significant than corresponding compromises. For instance, although the Vapur water bottle is much less stiff than a regular rigid water bottle, the reduced rigidity is rarely a problem. The Vapur bottle was still rigid enough to maintain the form of a water bottle yet soft enough to be flattened and rolled up when empty. Also, the urban users of the Strida folding bicycle we interviewed felt that the benefit of being able to bring the bike indoors instead of leaving it unattended outside, enabled by its foldability, far exceeded the drawback of slower riding speed.

8.2 Occupying Volume Efficiently in Shared Spaces

Transformation enabling size change was most benefical when the transformable product occupies space that is shared with other objects or people. Transformable products that can occupy shared spaces efficiently (i.e., by applying the expand/collapse principle) facilitates the use of environmentally preferred modes of mobility, which often impose the need to manage a limited amount of space. We provide two examples below.

1) People who do not drive, but instead walk, bike, or use public transit often must carry personal items, likely in a bag, with a much smaller capacity than a car. The expand/collapse principle enables one to minimize the volume of carried objects. For instance, the flattening feature of the Vapur water bottle and the foldability of the Dahon bike helmet were especially useful when they shared the internal space of a bag with books and a laptop.

2) Those who walk, bike, and use public transit have less personal space than drivers, especially during peak times. Therefore, in addition to being required to carry objects personally, the carried objects are also expected to be small enough to not extend into others' personal space. Transformation can help achieve such compactness. For example, the Strida bike's foldability allows it to take up much less space in a packed subway train, thereby disturbing other passengers less.

Generalizing, the value of volume minimization enabled by transformation depends on how much volume the product can occupy in a particular shared space. This also applies to products that are less relevant to ESB. For instance, a recently developed compact car uses a folding mechanism to minimize the amount of parking space that it occupies [16]. Another example is fighter jets that fold their wings upward to save deck space on aircraft carriers.

9 OVERALL CONCLUSION

Overall, we have the following conclusions. Transformable products can complement, or at least fill the gap for, infrastructure to enable environmentally significant behavior. However, function is sometimes compromised by transformation principles. It appears that for at least some products, the more portable and thus available for spontaneous use, the worse it performs compared to the less portable version. The folding bicycle offers more flexibility but performs less well than a standard bicycle for its core, riding function. A collapsible coffee cup or water bottle is more convenient to carry, but performs less well than a standard reusable coffee cup or water bottle. Even noncollapsible versions of products we are accustomed to being collapsible provide benefits. For example, a more rigid backpack can remain upright without support, a surprisingly useful feature.

As an example of infrastructure to support ESB, an alternative to the folding bicycle is the bicycle rental system that is available in several cities, shown in Figure 11. Such bicycles remove the burdens of maintenance, storage and theft. In addition, they need not be carried around like a folding bicycle. However, just as the success of public transit depends on its wide spread availability, the success of bike sharing systems depends on availability of bikes near one's origin and possibility of return near one's destination.

Figure 11: BIXI rental bicycle rack in Toronto.

The ideal situation to reduce reliance on disposable products is that reusable options are available at the point of use, to enable spontaneity without the hassle of carrying an often-compromised version of a product at all times. Another example is the eco-tray container offered by University of Toronto Cafeterias, shown in Figure 12. For a nominal deposit, a diner can choose to have their food served in an eco-tray rather than disposable packaging. The deposit is returned upon return of the eco-tray, which need not be immediate. The eco-tray addresses several concerns that establishments have with consumers bringing their own reusable containers. First, food servers are acquainted with the standard tray and know how to portion using it. Second, because the establishment is responsible for cleaning the trays, having control over this process reduces concern that unsanitary containers can cause illness in those who consume their food. However, since the eco-trays need not be immediately returned, they may not always be available. The handling of dirty versus clean eco-trays also presents additional tasks for cafeteria workers.

Figure 12: Reusable “eco trays” in cafeterias (blogs.studentlife.utoronto.ca/lifesigns/tag/eco-trays/).

Other infrastructure possibilities that enable ESB include carts that can be available for a deposit from stores, such that they need not be owned, nor must they be returned immediately, which detracts from their convenience. Similar to the eco-tray, incentive for early or at least predictable return is also required to ensure availability.

10 SUMMARY

This paper explored the relationship between transformation principles and ESB by applying lead-user methods. Testing five existing and two newly developed transformable products confirmed that they assist in ESB by increasing portability and spontaneity in using the products. By enhancing portability, one can more easily reduce reliance on disposable products, and use environmentally preferred modes of mobility more flexibly and spontaneously. In addition, transformation principles can encourage ESB by: 1) occupying volume more efficiently in shared spaces, 2) enabling various carrying and transporting methods, and 3) adding a new ESB-related function to commonly used products. We conclude that transformable products do aid in overcoming obstacles to ESB that are not yet addressed by appropriate infrastructure.

11 ACKNOWLEDGMENTS

The authors are grateful to the Natural Sciences and Engineering Research Council of Canada for financial support of this work.

12 REFERENCES

[1] Stern, P. C. (2000): Toward a Coherent Theory of Environmentally Significant Behavior, in: Journal of Social Issues, Vol. 56, No.3 2000, pp. 407-424.

[2] Singh, V., et al. (2009): Innovations in Design Through Transformation: A Fundamental Study of Transformation Principles, in: ASME Journal of Mechanical Design, Vol.131.

[3] Gu, P., Xue, D., Chen, Y. (2010): Global Product Development, in: Proceedings of the 20th CIRP Design Conference, Nantes, France, pp. 26-40.

[4] Hannukainen, P., Hölttä-Otto, K. (2006): Identifying Customer Needs – Disabled Persons as Lead Users, in: Proc. ASME Int. Design Engineering Technical Conferences, Philadelphia, PA, DETC2006-99043.

[5] Lin, J., Seepersad, C. (2007): Empathic Lead Users: The Effects of Extraordinary User Experiences on Customer Needs Analysis and Product Redesign, in: Proc. ASME International Design Engineering Technical Conferences, Las Vegas, NV, Paper No. DETC2007/35302.

[6] Srivastava, J., Shu, L. H. (2011): Encouraging Environmentally Conscious Behaviour Through Product Design: the Principle of Discretization, in: Proc. ASME 2011 International Design Engineering Technical Conferences, Washington, DC, DETC2011-48618.

[7] Ioannou, K., Veshagh, A. (2011): Managing Sustainability in Product Design and Manufacturing, Glocalized Solutions for Sustainability in Manufacturing, in: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Braunschweig, Germany.

[8] Fargnoli, M., Kimura, F. (2007): The Optimization of the Design Process for an Effective Use in Eco-Design, Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses, in Proceedings of the 14th CIRP Conference on Life Cycle Engineering, pp. 59-64.

[9] Anderson, C, Istchenko, A., Loberto, N., MacNeil, C., Martin, T., Ryan Peruzzo, R. (2007): Helmet Design Alternatives for Casual Bicycle Users, Term Project Report, MIE440F: Mechanical Design Theory & Methodology, Dept. of Mechanical/Industrial Engineering, University of Toronto.

[10] Lam, T. (2008): Environmentally Significant Behavior – Travel Mugs, B.A.Sc. Thesis, Applied Science and Engineering, University of Toronto.

[11] Son, J. (2010): Designing a Baby Stroller for Public Transit Users, B.A.Sc. Thesis, Applied Science and Engineering, University of Toronto.

[12] Interview: Strida bike designer Mark Sanders, dezeen magazine article. (2008): URL: http://www.dezeen.com/2008/02/03/interview-strida-bike-designer-mark-sanders/ (last accessed January 30, 2012).

[13] Sanders, Mark. A. (1985): The Design of a New Folding Bicycle, Masters Thesis, Industrial Design Engineering, Joint program between Imperial College and Royal College of Art.

[14] Move-it cardboard cart. (2010): designboom, URL: http://www.designboom.com/weblog/cat/8/view/11163/move-it-cardboard-cart.html (last accessed January 30, 2012).

[15] Converter Solar Backpack product description, Voltaic, URL: http://www.voltaicsystems.com/converter.shtml (last accessed January 30, 2012).

[16] Hiriko – Driving Mobility, URL: http://www.hiriko.com/ (last accessed January 30, 2012).