Chapter 2
Time Axis Design as an EcoDesign Method

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Abstract Time axis design is a design method with which a designer considers temporal changes of social situation, surrounding environment of design objects, users (including their values), and design objects. Although some products were designed with considering temporal changes, the concept of time axis design is not well organized until now. For clarifying the basic concepts of time axis design, this paper first illustrates cases of time axis design and extracts indispensable elements of time axis design. Second, this paper proposes a time axis design support method. Third, as a case study, this paper illustrates time axis design of umbrella. As a result, this paper shows that the proposed design method is effective in stimulating a designer for deriving design ideas.

Keywords Time axis design · Design methodology · Scenario

2.1 Introduction

Since the current manufacturing paradigm cannot get out of the mass production and mass consumption in correspondence with diversification and expansion of customer needs, today's manufacturing industry causes many problems such as sustainability issues typified by SDGs (United Nations 2015). The conventional design theory used in today's manufacturing is not sufficient for these problem because it does not concern about our values to products. For solving this problem, we study "time axis design," which explicitly deals with temporal changes in design (Matsuoka 2012).

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Y. Kishita et al. (eds.), *EcoDesign and Sustainability I*, Sustainable Production, Life Cycle Engineering and Management, https://doi.org/10.1007/978-981-15-6779-7_2

Design objects designed with the time axis design can respond to temporal changes. By introducing the view of time axis in design object, the designer can correspond with the changes of value we do not expect now. However, at present the concept of time axis design is not organized well.

The objective of this paper is to clarify the concept of time axis design and propose a method of time axis design applicable to various products. In this paper, we describe a method to find out time axis design solutions based on collected cases of time axis design.

The rest of this paper is structured as follows. Section 2.2 describes the role of time axis design for eco-design. Section 2.3 summarizes research efforts on time axis design. Section 2.4 describes cases of time axis design cases. Section 2.5 proposes time axis design method based on the collected cases. Section 2.6 shows a case study of time axis design. Section 2.7 discusses the effectiveness and challenges of the proposed method. Section 2.8 concludes the paper.

2.2 The Role of Time Axis Design for Sustainability

As discussed in SDGs and Circular Economy (CE) (European Commission 2015). One of the most important issues for sustainability is the design of value supply system considering future effects such as resource depletion and global warming. This requires product design for longer use in order to avoid resource depletion. However, the conventional product design was to design a product so as to perform the best at the beginning of use. Therefore, (Takahashi et al. 2011) proposed the concept of time axis design to cope with sustainability issues; for realizing time axis design, he proposed multi-space design model representing relationship between a design object and the places of use, and multi-timescale model expressing temporal changes of products with multiple temporal magnitudes. By introducing "time axis" to product design including support systems that enable the product to address temporal changes, we can design products that work longer and cope with sustainability issues typified by SDGs and CE.

In the context of eco-design, we considered about the extension of product life. Daimon et al. (2003) proposed decision support method for life cycle strategy by considering product physical lifetime and value lifetime. This discussion is a typical example of time axis design, while we were not aware of the concept of time axis design at that time. Moreover, if we discuss extremely, all sustainability issues are related to temporal changes, and the essential conflict resides within different time scales; for example, resource depletion and global warming in long time scale and pursuing quality of life in relatively short time scale.

So, by introducing the concept of time axis design, we can discuss such temporal changes in the context of design in an integrated and systematic manner.

2.3 Time Axis Design

In this paper, we describe the framework of time axis design as shown in Fig. 2.1. The designer designs a product service system so as to provide service to a user and the user feels the value from the service. In the modern context of product design, as service engineering Tukker (2004) says, we should understand that a product more or less consists of hardware and service provided by human. In this paper, we take product service systems as design objects. In the places of use, various artifacts and natural objects exist and interact each other in addition to the designed product. In this situation, we can find out various temporal changes including temporal changes of the design object, the changes of the user, the changes of the place of use, and the changes of social situation. The changes of the design object (i.e., a product service system) include the temporal changes of hardware, such as degradation and failure, and the changes of service such as the improvement of the service. The changes of the user include physical changes such as growing tall and mental changes such as changes in preferences. In addition, we consider that the places of use, in other words the environment surrounding the product service system, also changes. Moreover, social situations such as legislation, fashion, and market environment also change.

The concept of time axis design is to design a product service system considering all of these kinds of temporal changes by introducing "time axis" to design space (Matsuoka 2012). In other words, from the viewpoint of time axis design, a product service system can provide value for users only when the state of these changing

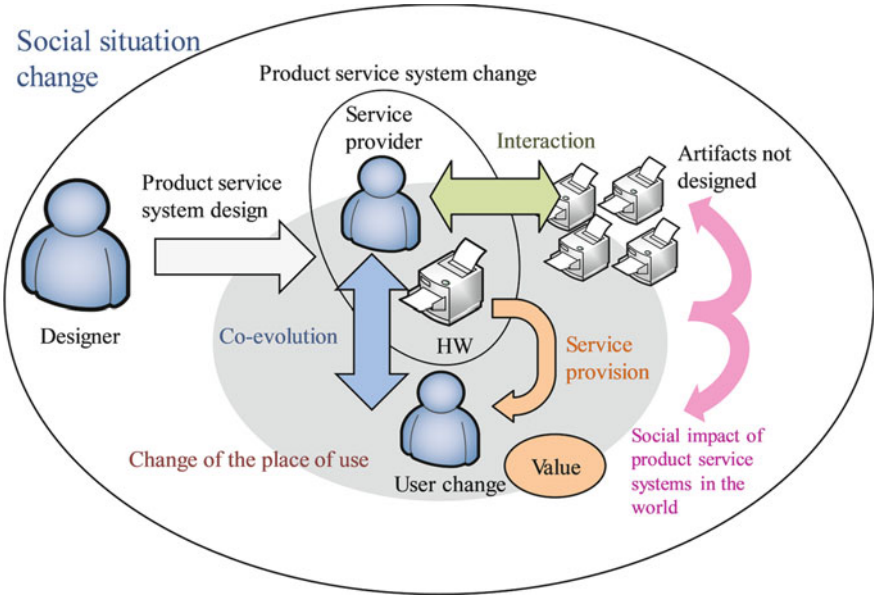

Fig. 2.1 Concept of time axis design

elements (the product service system, users, places of use, and social conditions) fulfill a certain set of conditions. We call such a set of conditions "value provision conditions." While the traditional design is to design a hardware product without considering all these types of changes, the time axis design is to design a product service system so as to satisfy the value provision conditions for a certain period of time with assuming all these types of changes.

For example, we have been studying upgrade design (Umemori et al. 2001), which extends the life of a product by upgrading some functions of the product at the use stage in response to changes of users' needs. We have also proposed self-maintenance machines (Umeda et al. 1995) that can recover indispensable functions by themselves when failure or degradation occur. They have built-in systems that can deal with problems that arise over time. We have developed these design methods without knowing the concept of time axis design. In this way, the concept of time axis design has not been discussed explicitly in the design community, although it is simple, clear, and very powerful tool for solving the sustainability issues.

2.4 Cases of Time Axis Design

2.4.1 Approach

This paper proposes a design support method for time axis design, based on cases we collected. This is because we assume that, when a designer faces a new problem, he or she looks for past similar cases like case-based reasoning (Agnar and Enric 1995).

Since there are few cases where the concept of time axis design is apparently utilized in their design at present, we collected the following cases through the Internet and literature as the cases of time axis design:

- The cases have some temporal changes.
- When some problems are caused by the temporal changes, some countermeasures are taken or countermeasures are installed in advance during design phase.

A total of 130 cases were collected. Table 2.1 shows typical 10 examples of the cases.

2.4.2 Classifying Time Axis Design Cases

We classified the collected cases based on the types of temporal changes and countermeasures for the temporal changes; Tables 2.2 and 2.3 indicate the types of temporal changes and the types of countermeasures, respectively. In this paper, we focus on temporal changes of users, design object, places of use. We do not discuss social

Table 2.1 Examples of time axis design cases

No.	Case name	Description
1	Message soap	A letter is embedded in the soap and when the user washes his/her body with the soap, the letter appears at a certain time
2	BABUBU furniture (http://shinse-i.jp/babubu/)	If the bed size does not fit a baby because of his/her growth, it is customized to a desk by applying additional parts
3	*Bonsai*	*Bonsai* refers to potted plants grown with special care for appreciation. A user can tailor the *bonsai* to his/her taste by taking care of it as the plant grows and the environment changes. (https://www.bonsaimyo.com/bonsai/Japanese/)
4	Copying machine	A copying machine is provided with maintenance service in case of trouble
5	LEGO (https://www.lego.com/en-us)	By preparing different sets of LEGO according to age, LEGO can respond to the changes in children's preferences
6	Wine	Wine is matured by storing it until it is ready to drink after purchasing it
7	Skype translation (https://www.skype.com/ja/)	As the AI learning, it leads to improve the performance of translation technology
8	Baggage made of bamboo	Bamboo used as material of a baggage is getting attractive as the user uses
9	Beaker pudding container (https://www.harioscience.com/)	By adding a measuring function in pudding container, the container can be used as a beaker after eating the pudding
10	Moist hair dryer: Areti (https://areti.jp/)	The dryer has the function to adjust air volume in response to the changes in the user's age and season

changes because it is ambiguous. By collecting and classifying the cases of time axis design, we made a matrix between the changes and the countermeasures as shown in Table 2.4. This Table 2.4 shows the number of the cases corresponding to each change and each countermeasure. Since the red cells in this Table 2.4 have enough number of cases, we consider that the countermeasure in this cell is effective to the change in this cell. And, we use these cells to find out design ideas in Sect. 2.6.

Table 2.2 Types of temporal changes (A-H)

Type of temporal change	Subtype of temporal changes	Example
Change of a user	(A) Change of the outside of a user	Growing tall
	(B) Change of the inside of a user	Change of user's taste preference
	(C) Switch of users	Used by different users
	(D) Change of behavioral pattern of a user	Change contents to match user needs
Change of a design object	(E) Change the structure/attribute of design object	Change of color of the design object
	(F) Change the information held by design object	Accumulating usage history in the design object
Change of the place of use	(G) Change the environment in the place of use	Change of temperature according to the change of season
	(H) Change the places of use by the user	Use the design object in different places

2.5 Design Support Method for Time Axis Design

2.5.1 Approach

In order to solve the problem mentioned in Sect. 2.3, we construct a support method for time axis design as shown in Fig. 2.2. In this method, a designer identifies temporal changes of a design object by examining the use case and derives countermeasures for the temporal changes. First, a designer defines a persona that uses the product service system to design. Then, the designer draws use case scenarios in which the persona uses the design object (see Sect. 2.5.2). The use case scenarios allow the designer to identify plausible temporal changes of the design object, users, and the place of use. Next, the designer identifies a type of temporal change for each temporal change with referring Table 2.2. At this time, the designer classifies the temporal change into two types of long timescale (year/month) and short timescale (one cycle of use of the design object) based on the concept of multi-time scale (Matsuoka 2012). Then, the designer selects countermeasures corresponding to the identified types of the temporal changes with referring Table 2.4. For supporting these steps, we constructed a database of the cases of time axis design we collected. The designer can refer the cases in Table 2.4 (see Sect. 2.5.3). Next, the designer finds out design ideas realizing the selected countermeasures. Finally, by selecting the design ideas and integrating them, the designer derives a design solution (see Sect. 2.5.4).

Table 2.3 Types of countermeasures (a–i)

How to respond	Type of countermeasure	Description	Example
Embed countermeasure in the design object	(a) Add a function to adjust	The design object has adjustable structure to cope with temporal changes	Height adjustable structure
	(b) Change of configuration of design object	The design object has structure in which multiple parts are combined or recombined	Structure that can be freely recombined to the size user needed
	(c) Make countermeasure service easier	The design object has a mechanism that allows users and service providers to execute service easily	Applying design for maintenance
	(d) Use the structure that have a function in self-maintenance	The design object has a structure that can return to its normal state after a failure happen	Structure that repairs scratches on the surface
	(e) Prepare multiple usages	The design object has potential functions	Pudding containers also has a function as measuring cup
	(f) Have a function to learn	The design object has a mechanism to change the behavior based on the accumulated data	Function to learn selection history of the user in the Internet shopping
	(g) Have a function to sense changes	The design object has a mechanism that senses temporal changes and notifies the user	Function to sense changes in the places of use with a change brightness
Create a system to respond as service	(h) Prepare countermeasure service	During use of the design object, services are provided to cope with temporal changes	Repair service is provided
Encourage the user to respond	(i) Provide the user with the opportunities to respond	Facilities and equipment are provided for users to cope with temporal changes as needed	Spare parts are prepared and the user replaces them with faulty ones

Table 2.4 The number of collected time axis design cases

		Types of countermeasures								
Types of temporal changes		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
	(A)	12	9	0	0	3	0	1	0	0
	(B)	11	7	0	0	4	20	15	6	6
	(C)	5	2	0	0	5	13	12	3	3
	(D)	12	12	0	0	6	13	11	6	4
	(E)	6	1	12	3	3	0	8	12	2
	(F)	7	0	1	1	5	50	14	7	3
	(G)	5	0	3	1	1	4	9	3	0
	(H)	4	3	1	1	3	0	3	4	0

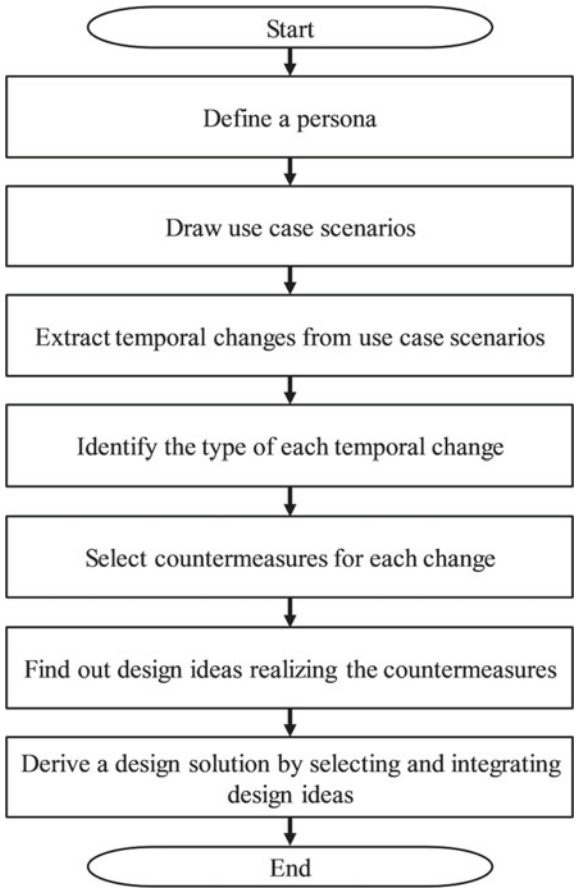

Fig. 2.2 Flow of time axis design support method

2.5.2 Define a Persona and Draw Use Case Scenarios

When considering temporal changes of a design object, it is necessary to consider the user who uses the product and the place of use of the product. In this method, the designer clarifies them by describing persona of a user and his/her use case scenarios.

2.5.3 Extract Temporal Changes from Use Case Scenarios, Identify Key, and Select Countermeasures

From the described use case scenario, the designer extracts all plausible temporal changes of the design object, the user, and the places of use. Second, the designer identifies a type for each extracted temporal change with referring Table 2.2 and classifies the temporal changes into two types of timescale.

Third, the designer selects countermeasures corresponding to the selected types of the changes.

By using the uniform expression about the type of the temporal changes summarized in Tables 2.2, 2.3 and 2.4 and the database of the cases, we think the designer can create design ideas efficiently.

2.5.4 Find Out Design Ideas and Derive a Design Solution

The designer finds out design ideas that can realize the countermeasures selected in Sect. 2.5.3. Then, by selecting appropriate countermeasures and integrating them, the designer derives a design solution.

2.6 Case Study

2.6.1 Problem Setting

We executed time axis design based on the proposed method in Sect. 2.5. In this paper, we take an umbrella as a design object. The reason why we choose an umbrella is that it is one of the most popular products daily used by everyone. Therefore, when proposing design ideas about an umbrella, we easily assume the shape, the size, and use case. In this case study, the product service system at the beginning is not clear.

2.6.2 Define a Persona and Draw Use Case Scenarios

We described the use case scenario as follows:

Persona

A Man, 30 years old, office worker

He often goes out for work with his umbrella in rainy days.

Use Case Scenario

On a sunny day, he does not use his umbrella. When it rains or snows all day, he uses his umbrella from his house to his office. He sometimes loses his umbrella on the public transportation. When the wind is strong, he closes the umbrella and stops using it. If he dares to use it, the umbrella might be flapped by the wind, breaking the bones and the surface cloth. When the same umbrella is used for long time, the bones of the umbrella become rusty and it becomes difficult to open and close. Furthermore, the bones are distorted according to time and the cloth also breaks, and the water-repellent function is deteriorated. When the umbrella can no longer prevent rain or he gets bored with the design of the umbrella, he replaces it with a new umbrella of desired color and stops using the old one.

We described this persona and use case scenario since we often see in daily life.

2.6.3 Extract Temporal Changes from Use Case Scenarios, Identify Key, and Select Countermeasures

Next, we extracted plausible temporal changes from the use case scenario and related them to types of temporal changes in Table 2.2. Then, we classified the temporal changes into two timescale. In this case study, the short time scale is one cycle for using an umbrella. Table 2.5 shows the results of this step.

For each type of temporal changes, we selected countermeasures by using Table 2.4 and the database.

2.6.4 Find Out Design Ideas and Derive a Design Solution

We found out design ideas for the countermeasures. Table 2.6 summarizes the design ideas.

As a result of integrating the design ideas, the result of devised design solution is described as below.

Design solution

The Umbrella is made of cloth that is more water-repellent when we use. The number of the bone can be changed and even if several bones are broken, it could be dealt with by the rearrangement. The umbrella can be changed to a raincoat according to the user's mood. If the bones get rusty or the cloth deteriorates, the

Table 2.5 Extracted temporal changes in the case study and their time scales

Patterns		Type of the time scale	Design ideas
Temporal changes	Countermeasures		
(B)	(e)	Short	Change raincoat depending on user's emotion
(D)	(a)	Short	Add an attachment that supports loads
(D)	(i)	Long	Provide a service that allows users to change to durable bones based on frequency of use
(E)	(d)	Long	Use water-repellent cloth
(E)	(i)	Long	Provide a service that allows users to repairs cloth
(G)	(h)	Short	Provide umbrellas rental service where users can borrow and return their umbrella when it's sunny
(H)	(b)	Short	Change the number of bones to cope with snow
(H)	(g)	Short	Add a function to notify users when the rain stops

Table 2.6 Examples of design ideas

Temporal changes from use case scenario		Type of the temporal change	Type of the time scale
User	Preferences change (get tired of umbrella design)	(B) Change of the inside of a user	Long Short
	The luggage changes (large/small)	(D) Change of behavioral pattern of a user	Long Short
Design object	In long time scale, umbrella broken (bones breaking and cloth breaks) and the condition of umbrella has changed (rusting and water repellent function deteriorated)	(E) Change the structure/attribute of design object	Long
	In short time scale, umbrella changes states (open to close)		Short
Places of use	Climate changes	(G) Change the environment in the place of use	Long Short
	Location changes due to the user's movement	(H) Change the places of use by the user	Long Short

provider prepare a product that allows users to repair. Provider also prepares a rental service that users can rent anywhere and return whenever the rain stops.

2.7 Discussions

The results of the case study show that attention to the types of temporal changes in a design object, a user, and the place of use, and their countermeasures contribute to the derivation of new time axis design ideas. In particular, we found that the use of a case-based design approach using the cases of time axis design was effective in deriving design ideas.

There are some remaining problems to be addressed. One is to validate our design support method. For example, we need to investigate our design solution really works. In response to these questions, we need to consider a validation method about our design support method.

Another problem is that the proposed design support method is case based and concrete, so it might be more abstract in order to increase generality.

2.8 Conclusion

In this paper, we clarified the concept of time axis design and proposed a time axis design support method, which aims to respond to changes in people's lives and sense of values as the temporal changes by introducing time axis concept into the design theory.

The design support method we proposed is based on 130 cases of time axis design we collected. In the proposed design method, plausible temporal changes are derived by drawing a use case scenario and design ideas are derived by utilizing the mapping between temporal changes and their countermeasures. As the case study, we illustrated the time axis design of an umbrella. By using the proposed method, several time axis design ideas were derived.

Future work will include validation of the derived design ideas and generalization of design support methods.

Acknowledgements This work was supported by the Grant-in-Aid for Scientific Research (No. 16K12667) from the Japan Society for the Promotion of Science.

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