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Paper:

Sustainable Design Implementation – Measuring Environmental Impact and User Responsibility

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Sustainable design in product development has multiple roles in addressing an increased level of sustainability. This includes reducing resource consumption and modifying user behaviors to become more eco-friendly. However, these functions are typically assessed separately, despite a proposed mutual correlation. This paper proposes a framework for defining this correlation. By using the correlated functions in parallel, one can enhance the product development process, and this will strengthen the use of sustainable design as a powerful design tool for future products. A practical approach for implementation is needed, which should show the benefit of the design both from the environmental aspect and a change in the responsibility of users. The primary goal of this manuscript is to propose an approach to fill this gap, using experiments to explore the effect of a washing machine modification project in Indonesia. Resource consumption while doing the laundry is measured as a representation of the environmental impact, while the users' predisposition for environmental responsibility inclination is analyzed by scaling the responsibility. The results show that the sustainable design strategy is effective in reducing the environmental impact, while simultaneously increasing the environmental responsibility of users. Further study is required to define the correlation between the measured factors to formulate a well-developed theory related to this correlation.

Keywords: sustainable design, eco awareness, environmental impact measurement

1. Introduction

Sustainable design as a concept of product design is useful in developing products with an increased level of sustainability, encompassing the environmental, social, and economic issues attached to a product. This concept has become widely discussed especially in the last decade, although implementation in industry remains in its infancy [1]. There are gaps between the ideal product concept and consumer acceptance that need to be urgently resolved [2, 3] since the inevitable environmental damage is increasing exponentially. Real actions to reduce these problems are highly sought after, including reduction of emissions, waste, energy consumption, and the consumption of other resources throughout the life cycle of the product.

Across the lifespan of a product, the usage phase generally holds an essential role in creating environmental impacts [4]. Interaction between users and products during this phase creates emissions and waste, and also consumes energy and other resources. Meanwhile, the intensity and pattern of this interaction depends on the users' behavior [5]. A single product used by multiple users with diverse behaviors, will result in differing impacts on the environment. Certain behaviors may lead to severe exposure of resources or excessive waste, while others may cause more moderate consequences. Based on this relationship, it can be concluded that behavior is a key factor in determining environmental impact.

Other studies also show a correlation between product design and the user behavior, revealing an opportunity for product designers to prompt users to more eco-friendly behaviors through their design [6, 7]. Strategies were created and tested for implementation in various products, and the results show that eco conscious behavior can be provoked. Studies related to this are known as design for sustainable behavior. Therefore, change of behavior becomes the intermediate goal leading to the environmental impact reduction. In addition, it offers educational value for users to have greater environmental responsibility after interacting with the product. One may consider the concept an investment towards a more permanent impact in influencing environmental responsibility through product design. It is thus worth discussing the concept further to create a wider implementation.

However, the chain reaction between the sustainable design, the users' environmental responsibility and the environmental impact is still barely described quantitatively in the implementation stage. In addition, product designers require a practical approach to incorporate this concept into the product development process. Particularly for small and middle industries, a framework should be proposed giving guidance in applying the concept. The primary goal of this paper is to propose an approach for implementing sustainable design concept by quantitatively expressing its correlation with consumer responsibility and the environmental impact so that it can simply be invoked by industries in their product development processes. In this paper, a framework and a practical approach are proposed and subsequently tested in a washing machine design modification project in Indonesia. The project was chosen due to its strong relationship with the people's daily cultural activities and also its significant impact on the environment, although it is frequently forgotten in its simplicity.

2. Related Works

2.1. Sustainable Design Implementation

Presently, there is an increasing awareness amongst product manufacturers about developing sustainable products, which requires integrated design frameworks and tools to bring the concept into reality [8]. In addition, regulations associated with a product's environmental impact are prolific in developed and emerging countries, imposing compliance by manufacturers [9]. There is a transition from old products to newer, more sustainable ones over time, in order to achieve the goal of future sustainability [10].

However, the transition process is not easy for the majority of stakeholders because it expands the considerations of the product development process, and the new considerations are mostly assumed to be an additional cost, although this assumption may not be accurate [11]. In addition, events and conditions across the entire life cycle of a product are crucial considerations in the process, including distinctive scenarios and behavior during the operational stage [12].

Due to this needs expansion, new frameworks are required to fill the gaps, regarding all facets of sustainability. Some methods focus on the direct environmental impact, while others focus on the social dimensions. The major challenge is combining these dimensions into an integrated framework, which is challenging due to the massive data volume and information to be synthesized.

2.2. Environmental Responsibility Measurement

Environmental responsibility has not been globally defined, although the terminology is well understood in common discussions. One definition states that it has a similar meaning to environmental awareness, behavior or consciousness, and it has several dimensions that can be measured qualitatively and quantitatively. Several dimensions mentioned in a prior study are cognitive, affective, conative, and behavior [13]. Another study added the dimensions of value and past behavior, related to a consumer's environmental responsibility towards a product [14]. These dimensions are detailed in some information presented to respondents, who subsequently gave responses related to the issues.

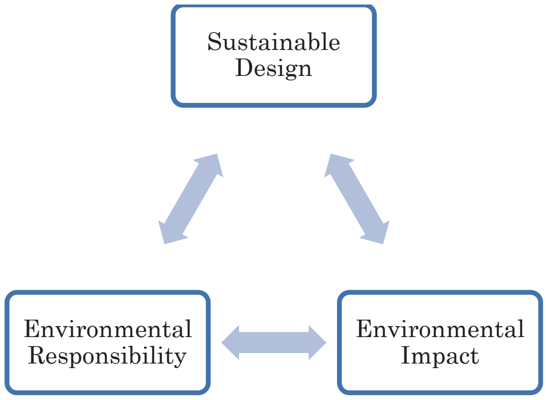

Fig. 1. The correlation triangle forming the framework of our study.

For a quantitative analysis, the Likert scale numbering 1–5 has been used previously in educational research, regarding students' cognitive and attitude abilities [15]. While other measurement tools such as the LT scale, SC scale, or MWB scale exist, the Likert scale offers a simple measurement method based on respondents' agreement or disagreement about a presented issue [16]. It has been widely used for various purposes, and has sufficient flexibility to be modified according to research requirements.

3. Framework and Approach

Sustainable design has been overwhelmed as a concept to reduce environmental impact in a product's life cycle. As a consequence, product design is affected by the environmental impact itself. It is a reciprocal correlation. Similarly, a designer adapts users' behavior by designing products, and reciprocally the design has the ability to influent users to behave differently according to certain factors. From an eco design perspective, the phenomenon is used for provoking product users to act in accordance with the environmental requirements, whether the user is aware or unaware, such as reducing resource consumption, or managing waste wisely [6, 7]. Thus the environmental impact and the behavior affect one another, forming an interesting triangle of correlation (**Fig. 1**). We propose this correlation triangle as a new framework for the sustainable design field.

This framework becomes the foundation of the proposed approach, using the interrelated function to design a system for supporting the sustainable design implementation. Nevertheless, not all relations can be explained by our approach at present.

The approach embraces four steps which are problem identification, solution selection, environmental impact measurement, and measurement of the consumer's environmental responsibility (**Fig. 2**). It is proposed to recognize the effectiveness of a product design-based solution in reducing environmental damage through technical and behavioral measurement. In this research, we use home

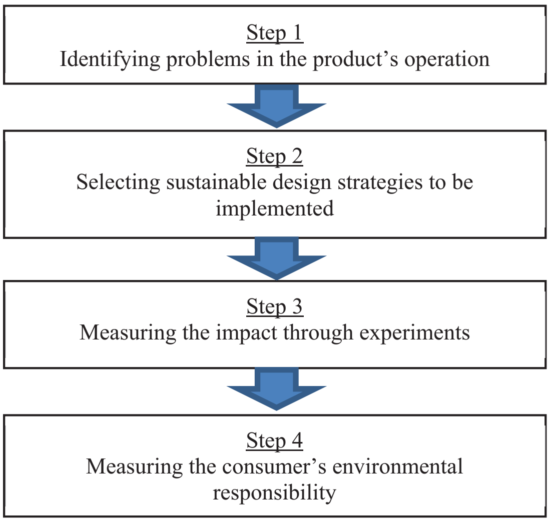

Fig. 2. The four step approach of our study.

laundry activity in Indonesian households as a case study. The steps of the approach are described below.

Step 1. Most Indonesian people do the laundry in their own homes, almost daily. Excluding other impact, the discussion is limited to the consumption of water and electricity, where the prominent resource is water. Water in Indonesian households is used for drinking, laundry, bathing, and other washing activities, where the primary water source is ground water wells owned by families. Household water waste is then streamed through the sewage system, which usually empty into a river. In majority of Indonesian cities, the waste water is not treated properly so rivers are polluted and the clean water stock is not replenished, resulting in reliance upon on rainfall. During the dry season, drought exacerbates the situation in some parts of Indonesian cities, and families have to suppress their washing activities.

Besides the lack of management and facilities, the pattern of poor resource consumption also arises from societal behavior. Limited awareness of environmental issues and cultural habits result in unnecessary activities, leading to increased waste [5]. People in Indonesia mostly use hands and twin tub washing machines to do their laundry, resulting in unmeasured water usage during the activities. In some cases, it may lead to excessive water consumption. However, an automatic single tub washing machine is considered expensive for most Indonesians. Thus, only a small percentage, under 3%, of Indonesian people utilize the single tub washing machine [17], despite it being known as a more eco-friendly way to do laundry.

Step 2. To overcome the environmental problems related to laundry, there are multiple solutions presented by previous studies. One can apply a sensor system to control the use of resources, and this strategy has actually been adopted by the single tub washing machine. Such machines limit the water usage based on the chosen mode and the weight of laundry, circumventing the users input to the process. Another alternative is to give feedback to users about the process output, providing information so users can include it as a consideration in doing the laundry, which is known as the eco information strategy [18]. This strategy does not directly control the process but provides input to the user's behavior, which is expected to affect the process afterwards. Once the consumer has consumed a large volume of resources, while he or she could see the consumption, the concept aims to invoke a guilty feeling in the consumer, hopefully leading to a more frugal action on the next use of the same product, thus it addressing sustainable behavior. Besides an easy installation to the existing machine or washing facilities, the strategy is considered to be suited to the local characteristics of local users [3]. Therefore, this is the strategy chosen for this study. The aim of the modification is providing a monitor near the machine or washing facility, displaying the real-time water and electric power consumption to users while they do the laundry. Subsequently, this modified design should be compared to the existing laundry processes done at present.

Step 3. The third step of the approach is the measurement of the environmental impact. In this research, the impacts to be investigated are limited into: water usage and electricity consumption. There may be other impacts related to the process such as detergent usage or disposal of machine components, but those are excluded from this discussion. Thus the research facility should be able to measure and record water usage volume and electricity consumption during the experiment, so that the data can be presented for further analysis. More detail is provided in the next section.

Step 4. Finally, the framework requires that users' environmental responsibility be quantified. The effect of the strategy is not expected to stop after the experiment. Since the strategy provides information, it is expected to have an education effect to the user. If the strategy can change the user's behavior during the process, it may have a longer impact or may result in a permanent effect on the users. However, an appropriate tool for measuring the change of users' environmental responsibility remains difficult to find. Therefore, in this paper we propose a new tool for measuring the users' environmental responsibility before and after their experience using the modified laundry machine.

4. The Measurement Methods

4.1. The Environmental Impact Measurement

The environmental impact of laundry activities can simply be identified by measuring the water volume and the electricity usage. In this study we conducted experimental research at a studio designed like a laundry spot in a typical Indonesian household, involving respondents from different backgrounds. Laundry spots in Indonesian houses may be located in the kitchen, near the traditional water well or in the bathroom, although in rural areas, we may find many people still doing laundry right on the

Fig. 3. Washing by hands and a twin tube washing machine.

Table 1. Profile of respondents.

Respondents' profile		Freq.
Gender	Male	4
	Female	8
Education level	Elementary school	0
	Junior high school	3
	Senior high school	4
	College	5
Age	18–25	2
	26–40	4
	>40	6

Table 2. The experiment activities.

Laundry activity	Description
Type 1 (A1)	Business as usual (BAU). Participant washes the clothes using the method as he or she typically performs in daily life.
Type 2 (A2)	The awareness strategy. Participant washes the clothes using the method as he or she typically performs in daily life, while seeing the resource consumption through a monitor.
Type 3 (A3)	The technology strategy. Participant washes the clothes using a low power front loading washing machine as a representation of high-tech utility in reducing resource consumption.

river. Furthermore, most people from middle and low income groups may use their hands or a twin tub washing machine, or a mixture of both methods (**Fig. 3**).

Replicating these conditions, all washing facilities are provided in the studio to accommodate the respondents' typical behavior, to be compared with the process using strategies as mentioned in the previous section. Subsequently, 12 respondents were recruited to perform laundry activities. The profile of the respondents is presented in **Table 1**.

Each respondent shall perform laundry activities three times, which comprise activities types 1, 2, and 3 as described in **Table 2**.

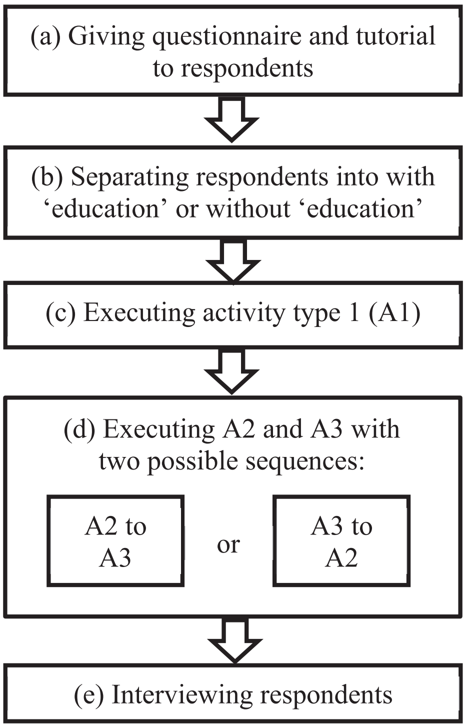

Fig. 4. The experimental flow.

The weight of clothes to be washed is set to be 3.5 kg in all activities. This weight is equivalent to the estimated amount of clothes used by a family of three (two adults and one child) in one full day or a period of 24 hours. The activities consume water and electricity that is measured and recorded to a data log system. Activity type 1 represents the participant's habit in daily life, while types 2 and 3 simulate the implementation of the mentioned design strategies.

These activities are to be accomplished in less than 6 hours by each participant. Activity type 1 is set as the first activity, while laundry activities types 2 and 3 are initiated alternately for every participant to avoid a sequential bias (**Fig. 4**).

Participants enter the studio individually and perform the activities alone, without being accompanied by the researchers. This allows more privacy for the participants, and to allow them do the laundry as usual. However, a camera is put inside the studio, by the respondents' agreement.

The experiment for each participant is begun with a tutorial session, followed by the participant filling a questionnaire to reveal the participant's background and understanding of the process and the related environmental issues.

In the next step, the participants are divided into two groups, those who receive 'education' and those who do not. The terminology 'education' here refers to a brief lecture and discussion between the researcher team and the participant about environmental problems, especially in the case of laundry at home.

We want to observe how this initial talk may evoke

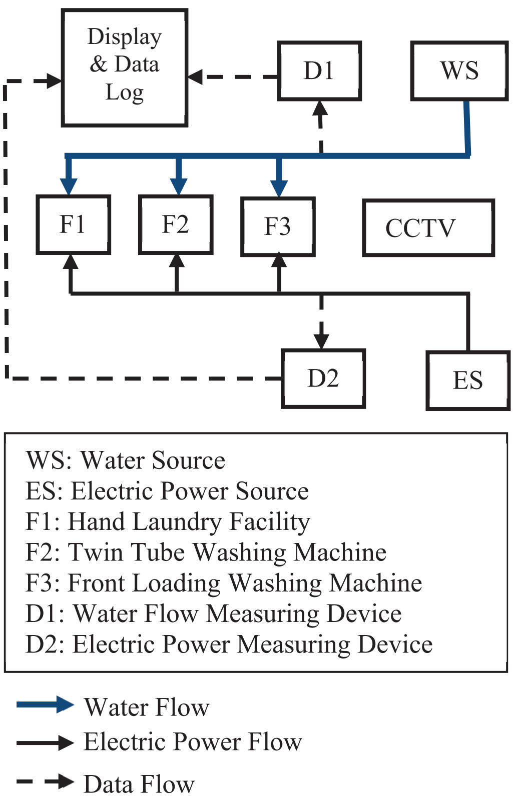

Fig. 5. A schematic diagram of the experiment.

awareness in the participants. Prior studies showed how consumers in Indonesia frequently need reminders to initiate their concern about environmental issues [5, 19]. Subsequently the three processes are initiated, and the experiment is ended with an interview to obtain the participant's perception during the activities (**Fig. 4**).

While participants do the laundry activity, the water and electricity consumption rate is measured and recorded using a data log system. The layout of the studio to support the experiment is depicted in **Fig. 5**.

Activities types 1 and 2 can be done in facility 1 (F1) or facility 2 (F2), while activity type 3 should be done in facility 3 (F3). A small LCD monitor is placed near F1 and F2 to display the amount of resource used in activity type 2, while it is turned off when a participant doing activity type 1.

The recorded data is subsequently analyzed to understand the effect of the design strategies to the resource consumption. Moreover, results from interview session are considered to be the most important to reveal the reasons and perception of each participant related to their behavior.

4.2. The Environmental Responsibility Measurement

Based on the findings above, participants can be classified into four groups of awareness, as seen in **Fig. 6**, divided by two axes: cognitive and affective.

In the first quadrant, group C represents the people who already have the knowledge, but still do not show any concern in their activities. This group is rarely persuaded to shift their consumption pattern, thus the technology strategy suits to this group. Meanwhile, group D is the ideal group of consumer, who have sufficient information in what they do related to the environment, and they take actions to address better sustainability in their daily life. They choose the best process to minimize the impact on the environment, based on their financial ability, and use the resources wisely. The proposed strategy has an opportunity to promote consumers from groups A and B to group D, symbolized by arrows 2 and 3 (**Fig. 6**). It is also possible to promote group A to group C (arrow 1), but other methods are required to convert C into D. These conversion efforts should be achieved through education and substantiation programs, which are beyond the scope of this paper.

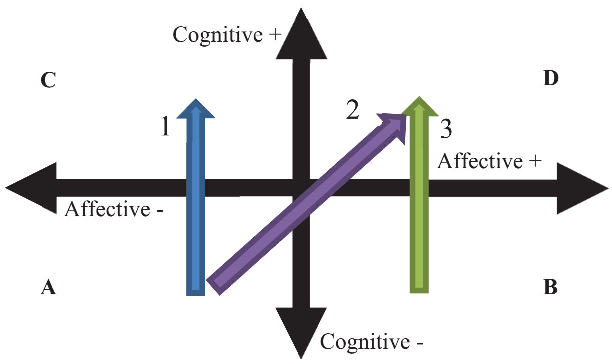

Fig. 6. Users responsibility mapping.

According to the explanation above, we can further formulate a tool to measure a user's environmental responsibility in his or her activities related to a product. However, in this discussion we use only the cognitive and affective dimensions as the representation of users' environmental responsibility due to their similar quantitative measuring ability. The conative and behavioral dimensions have more complex considerations, which are sometimes abstractly explained. Cognitive and affective aspects can be represented quantitatively by the user on a scale, for example from 1 to 5. The range of the scale is variable based on the accuracy requirements. For example, a similar method has been used for measuring a product's ability to fulfill users' basic needs [20]. For each issue, users can express their disagreement or agreement by choosing number 1 (strongly disagree, the issue does not represent my condition at all) or numbers 2–5, where a larger number shows the increased agreement to the presented issue. The arrangement of the issues in this study is shown in **Table 3**.

5. Results and Discussion

The experiment was conducted in August 2021 in Bandar Lampung city, Indonesia. Twelve participants were involved with profiles as described in **Table 1** and the re-

Table 3. Responsibility measurement scale.

Aspect	Issues	Measurement scale (1 to 5)	
		Before	After
Cognitive	1. Knowledge of whether the respondent knows that his or her laundry activity is harmful to the environment. 2. Knowledge of whether the respondent understands that there are more eco-friendly ways to do the laundry. 3. The respondent knows that there are other types of tools to do the laundry in a more eco-friendly way.		
Affective	1. Whether the respondent feel bad (sad, disappointed, or angry) about the impact of his or her laundry activity on the environment. 2. Whether the respondent feel good (happy, satisfied) when knowing he or she behaves more eco-friendly in doing his or her laundry 3. Whether the respondent feels concern about the long-term effect of his or her laundry activity's impact on the environment.		

source usage data is presented in **Table 4**, while graphs are given in **Figs. 7** and **8**.

Participants who used to wash by hand are marked with 'h,' while those who do their laundry using a twin tub machine or a mix between hand wash and machine wash are marked with 't' and 'm,' respectively.

5.1. Water Usage Measurement

It is found that the participant responses varied substantially. Three respondents were found to habitually use less than 50 liters of water doing laundry, while three others used more than 150 liters in their first activity (BAU). One extreme user consumed 351 liters during the process. The remainder fell between these extremes. One related term has emerged from the interview session, namely 'cleanliness perception.' Participant's perception about clean clothes has determined their behavior in doing laundry. This perception may come from accepted historic information and intuition, which further shape the action [21].

Our data shows that participants with higher educational backgrounds seem to have a higher standard of hygiene than those with a lower education. In this study, four participants were housemaids (participants 3, 4, 5, and 6) representing lower educational background and were given the same education. Although the influence of the respondents' background on their responses is interesting, it has not yet been investigated properly. The data is considered insufficient to reach a conclusion, thus discussion of this is saved for future work. The strategy interfered with the users' risk perception by providing more data to the user and forms new perceptions during the process.

After revealing the usage habit, we find that 9 out of 12 respondents willingly reduced their water consumption while interacting with activity type 2, while 3 others did not. Notably, the last three respondents were not given 'education' before the activities, therefore there is no regret for the large consumption. Despite stating their surprise about the volume of water, the interview results indicate ignorance of the environmental issues. However, all participants with 'education' have reduced their water usage during activity type 2, and intensely discussed how to maintain the pattern of reduced water consumption in their daily activities. Some succeeded in saving a large volume of water in activity type 2 in comparison to type 1, including the participant who has previously used 351 liter of water. Moreover, these nine participants also expressed their interest in having a measuring device at their home, so they can control the water consumption on their own in future. On this point, the awareness strategy has an opportunity to be developed further in improving the sustainability of household activities.

Notably, activity type 3 shows an almost constant water usage due to the control system of the machine. Slightly differing amounts of water in each participant's results are determined by the working mode chosen by the participants in each activity. Overall, this technology strategy worked impressively in reducing water usage. Moreover, the performance of the machine does not depend on users' perception. Unfortunately, the machine's water saving ability is not widely recognized in Indonesia, while the machine's price is perceived as expensive. While economic considerations are important in the Indonesian market, a subsidization policy from the authorities is proposed as a solution to implement this strategy widely. In addition, manufacturers should market the benefits to consumers more aggressively. Regardless of the price aspect, we argue that extensive use of this machine would significantly reduce the clean water provision situation in high population density cities in Indonesia.

5.2. Electricity Measurement

The amount of electric energy used is defined by the machine's motor specifications, the work load, and its usage duration. Moreover, the work load and duration depend on users' behavior, so energy consumption will also be determined by habit and perceptions of consumers.

Based on the interview, we find that energy consumption is a crucial consideration for the participants in determining the washing method. Even though the electricity price in Indonesia is categorized as low in comparison to other countries in South East Asia, most participants assume the electricity cost is a heavy burden on the family. As a result, some of them still prefer to wash by hand, or mix between hand wash and a machine to save electricity. While washing by hand does not require electricity, according to the measurements activity type 3 signifies the most favorable result compared to the twin tub machine performance. This data was surprising for the participants because they thought a machine with more complexity would require increased energy. Subsequently, after knowing the data and multiplying it by the electricity

Table 4. The measurement result.

Participants	Education before experiment activity	Mode in A1	Water usage [liter]			Electricity usage [kWh]		
			A1	A2	A3	A1	A2	A3
1	None	t	142	153	40	0.17	0.17	0.07
2	None	t	68	68	19	0.12	0.12	0.03
3	None	h	94	100	34	0	0	0.07
4	None	t	40	20	35	0.04	0.03	0.05
5	None	m	113	100	35	0.05	0.05	0.06
6	None	h	41	40	19	0	0	0.03
7	Yes	m	169	119	40	0.06	0.05	0.07
8	Yes	h	100	37	38	0	0	0.06
9	Yes	h	49	21	20	0	0	0.03
10	Yes	t	168	156	40	0.19	0.18	0.07
11	Yes	h	351	132	40	0	0	0.08
12	Yes	t	102	76	39	0.16	0.15	0.07

h = Participant performs BAU using hands only
t = Participant performs BAU using a twin tub washing machine
m = Participant performs BAU using a mixture of hands and a twin tub washing machine

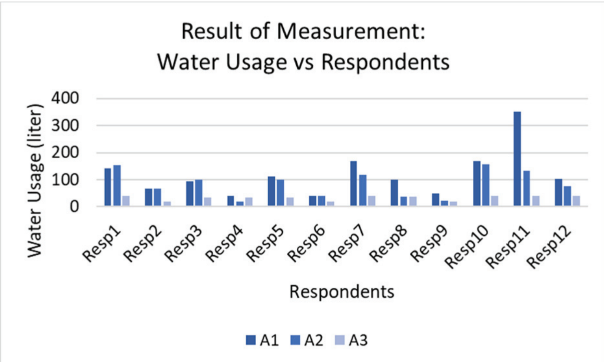

Fig. 7. Water usage for each respondent.

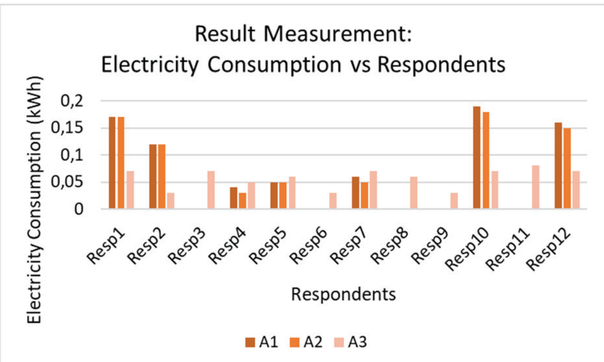

Fig. 8. Electricity consumption for each respondent.

price, most participants agree that using a washing machine does not cost them much. Nevertheless, all of them stated that currently they cannot afford the front-loading washing machine, due to the prohibitive price.

5.3. Environmental Responsibility Measurement

The questionnaire is completed by the respondents directly before and after the experiment. The summary of the results is presented in **Table 5**.

Overall, all respondents experience positive progress in each aspect after the experiment (**Fig. 9**). This means that the machine design modification had a positive influence on the users' environmental responsibility, even if the effect varies for each individual. The disparity between the respondents relates to the amount of responsibility inclination, but none of the aspects experience stagnation. This means all respondents have improved in cognitive and affective dimension simultaneously, but to differing extent.

The cognitive aspect has a higher inclination, varying by 2.1 points, while affective has lower variance of only two points. This means the respondents experience more improvement in their knowledge in comparison to their feelings. At most, after the experiment the respondents understood that laundry activities are potentially harmful to the environment (issue 1, **Table 3**), whilst before they were partially unaware of this potential impact.

The experiment has successfully provided new insights related to the importance of environmental issues in laundry actions, as one of their daily routines. They also became more concerned about these issues, shown by the inclination of the affective aspect. Some of the respondents said that they were shocked and sad knowing the amount of water they had used before. This becomes a trigger to make further commitments in improving the way they do the laundry in the future. All of the respondents declared their desire to use less water, but not all of them committed to changing their appliance because of the price.

The change of responsibility of the process is illustrated in the map as given in **Fig. 10**. This means the design modification project has moved the respondents from group A into group D, where they have felt increased responsibility for the environment. This result conforms to the resource consumption measurement, thus supporting the proposed framework.

Table 5. Responsibility measurement result.

Aspects	Issues	Average value of response		Variation of scale	Average value of aspect		Variation of scale
		Before	After		Before	After	
Cognitive	1	1.8	4.1	2.3	2	4.1	2.1
	2	2.1	4	1.9			
	3	2.1	4.1	2			
Affective	1	2.2	4.1	1.9	2.3	4.3	2
	2	2	4	2			
	3	2.5	4.7	2.2			

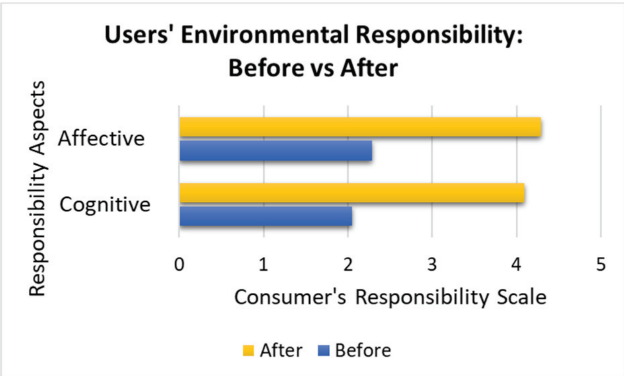

Fig. 9. Consumer responsibility before and after the experiment.

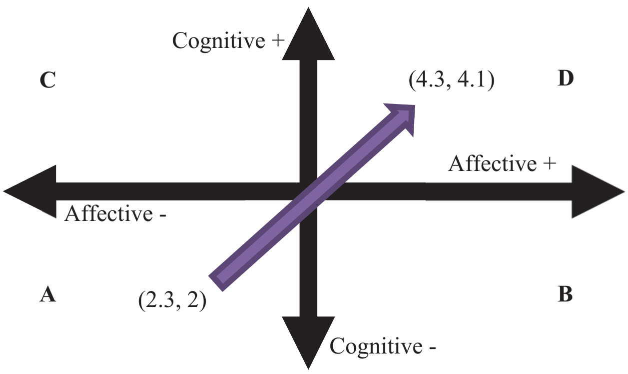

Fig. 10. Results mapping.

6. Conclusions

In this paper, a new framework and a practical approach were proposed and tested in order to implement the sustainable design concept by involving environmental impact and users' environmental responsibility simultaneously. As a case study, home laundry processes in Indonesia were chosen. A set of measurement tools is established in through the experimental procedure and questionnaires. This was applied in a series of studio-based experiments involving 12 respondents. After analyzing and choosing a strategy as a solution, the strategy was implemented. The results showed that the strategy implementation has a strong relation to the amount of resources exploited in a household laundry process, especially water, where the consumption volume was reduced significantly during the experiment. At the same time, the strategy is proven to bring users to a higher level of responsibility, encompassing the cognitive and affective aspects.

The approach implementation has successfully presented the impact of sustainable design on environmental impact and user responsibility simultaneously. Environmental impact and user responsibility are congruently affected congruently, thus showing the correlation as described in the proposed framework.

We can conclude that the implementation of the sustainable design concept in household products can reduce the negative impact on the environment, while simultaneously increasing the environmental responsibility of the users. In this study, it significantly reduced the water consumption in laundry activities and also provided an educational effect to the users. Thus, the effect may be permanent, forming a better consumption pattern.

Further, the data can be used by the designers in the product development process as considerations to continue the project to a business level. Meanwhile from the academic perspective, the approach can be improved to show the reciprocity effect between the dimensions in addressing new innovation for the community.

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References:

[1] T. Bhamra and R. J. Hernandez, "Thirty years of design for sustainability: an evolution of research, policy and practice," Des. Sci., Vol.7, e2, 2021.

[2] S. Kauppi, I. N. Pettersen, and C. Boks, "Consumer acceptance of edible insects and design interventions as adoption strategy," Int. J. of Food Design, Vol.4, No.1, pp. 39-62, 2019.

[3] I. Ghazali, S. H. Abdul Rashid, S. Z. Md Dawal, H. Aoyama, A. E. Tontowi, and R. A. R. Ghazilla, "Green product preferences with respect to cultural influences: empirical study in Indonesia," Int. J. Automation Technol., Vol.12, No.6, pp. 842-852, 2018.

[4] A. Mayyas, M. Omar, M. Hayajneh, and A. R. Mayyas, "Vehicle's lightweight design vs electrification from life cycle assessment perspective," J. of Cleaner Production, Vol.167, pp. 687-701, 2017.

[5] A. Hamni, A. Y. T. Panuju, and D. A. S. Ambarwati, "Understanding consumer's behavior for reducing environmental and social impact through sustainable product design – a study case of vehicle usages in Indonesia," IOP Conf. Ser.: Earth and Env. Sci., Vol.739, 2021.

[6] T. Bhamra, T. Tang, and D. Lilley, "Design for sustainable behaviour: using products to change consumer behaviour," The Design J., Vol.14, No.4, pp. 427-445, 2011.

[7] J. Daae and C. Boks, "A classification of user research methods for design for sustainable behaviour," J. of Cleaner Production, Vol.106, pp. 680-689, 2015.

[8] E. Kunii, T. Matsuura, S. Fukushige, and Y. Umeda, "Proposal of consistency management method between product and its life cycle design," Int. J. Automation Technol., Vol.6, No.3, pp. 272-278, 2012.

[9] M. Fargnoli, "Design process optimization for ecodesign," Int. J. Automation Technol., Vol.3, No.1, pp. 33-39, 2009.

[10] P. Ghisellini, C. Cialani, and S. Ulgiati, "A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems," J. of Cleaner Production, Vol.114, pp. 11-32, 2016.

[11] G. Latupeirissa and D. Adhariani, "External and internal economic impacts of eco-innovation and the role of political connections: a sustainability narrative from an emerging market," J. of Cleaner Production, Vol.258, 120579, 2020.

[12] K. Fujimoto, S. Fukushige, and H. Kobayashi, "Data assimilation mechanism for lifecycle simulation focusing on process behaviors," Int. J. Automation Technol., Vol.14, No.6, pp. 882-889, 2020.

[13] M. Ham, D. Mrčela, and M. Horvat, "Insights for measuring environmental awareness," Econviews, Vol.29, No.1, pp. 159-176, 2016.

[14] K. M. R. Taufique, C. B. Siwar, B. A. Talib, and N. Chamhuri, "Measuring consumers' environmental responsibility: a synthesis of constructs and measurementscale items," Current World Environment, Vol.9, No.1, pp. 27-36, 2014.

[15] H. Mahat, M. Hashim, N. Nayan, S. B. Norkhaidi, and Y. Saleh, "Development of environmental awareness measurement instruments through education for sustainable development," Proc. of the 8th UPI-UPSI Int. Conf. 2018 (UPI-UPSI 2018), pp. 73-86, 2019.

[16] S. M. Crus and B. Manata, "Measurement of environmental concern: a review and analysis," Front. Psychol., Vol.11, 363, 2020.

[17] CLASP, "Indonesia Residential End Use Survey," p. 193, 2020. https://clasp.ngo/publications/indonesia-residential-end-use-survey [Accessed December 20, 2021]

[18] J. C. Tu, Y. Nagari, and M. Shih, "Establishing design strategies and an assessment tool of home appliances to promote sustainable behavior for the new poor," Sustainability, Vol.10, No.5, 1507, 2018.

[19] A. Y. T. Panuju, D. A. S. Ambarwati, and M. D. Susila, "Implications of automotive product sustainability on young customers' purchase intention in developing countries: An experimental approach," IOP Conf. Ser.: Mater. Sci. Eng., Vol.857, 012024, 2020.

[20] H. Kobayashi, S. Fukushige, and H. Murata, "A framework for locally-oriented product design using extended function-structure analysis and mixed prototyping," Global Environment Research, Vol.25, pp. 43-50, 2021.

[21] A. Bearth, L. Miesler, and M. Siegrist, "Consumers' risk perception of household cleaning and washing products," Risk Analysis, Vol.37, No.4, pp. 647-660, 2016.

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• "A Simulation Methodology for a System of Product Life Cycle Systems," Adv. Eng. Informatics, Vol.36, pp. 101-111, 2018.

• "Living-sphere Approach for Locally Oriented Sustainable Design," J. Reman., Vol.8, Issue 3, pp. 103-113, 2018.

• "Strategic Evolution of Eco-products: A Life Cycle Planning Methodology," Res. Eng. Des., Vol.16, Nos.1-2, pp. 1-16, 2005.

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