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AN IMPROVED DESIGN OF A SOYBEAN PEEL SEPARATOR FOR TEMPE PRODUCTION

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Abstract: Tempe is a typical food of Indonesia which is consumed by people throughout the world. Tempe is made of fermented soybean by *Rhizopus sp*. The production of tempe is labor intensive. Among the twelve core stages in tempe production. One of that is separating the peel of soybean which is performed by human energy. It is hard to make contamination-free tempe since manual operation is involved in the process. This research was conducted by reverse engineering method with the aim to redesign an existing soybean peeling separator base on the user needs. The cycle time of whole tempe production to detect the problem were calculated. The longest time is peel separating process which use 40% from the whole tempe production. This station will be examined deeply an calculated per work elements and classify these elements to be the criterion of the developed machine. These criterion generate various design concepts, then each design will be chosen using scoring concept, screening concept, and feasibility to be realized. The results revealed that, the newly designed peel separator decreased the processing time by 39%, which decrease the risk of contamination by manual operator. In addition to that, the reduction of cycle time was decreased the water and electricity use of tempe production.

Keywords: contamination, peeling process, reverse engineering, soybean, tempe

Introduction

Tempe is a traditional food of Indonesia that has high protein level even compared to beef steak The protein content of 100 g cooked tempe is 2.05 g which is larger than the protein content of sliced beef steak of same weight (US Department of Agriculture, 2018). An animal study with rats showed that, tempe prepared with *R. stolonifer* has beneficial effects on liver function when they were fed with high-fat diets (Kameda, *et al*, 2018)

Based on the production process of tempe, the production floor is divided into 2 areas, namely dry and wet area. The following process were carried out in wet areas; sorting, boiling, soaking, cleavaging, skin separating, shoots separating, and washing. These process consume a lot of water to complete the process.

Skin separation process performed which separates the skin from soybeans. In this process, the operator manually separates the peel by immerse the soybean with the sieve into the water tank that is rotated with 60 rpm. Afterwards, the floating-peeled skin on the water surface will be collected using the sieve.

The process of separating soybean skin can be seen in Figure 1. Then beans will be entered into the shoots separation and washing area.

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Figure 1. Manual method of peel separating process from soybean.Contamination of raw materials with microbes and pathogens through manual handling has a detrimental effect on the quality of the final product. Most outbreaks of staphylococcal food poisoning follow the handling of cooked foods by persons who carry enterotoxigenic staphylococcal in their nares or skin and outbreaks of foodborne salmonellosis from raw to cooked foods or to foods not subjected to further cooking via hands. (Angelillo *et al.* 2000). Kadariya also has a focus on food-borne disease mention: "Staphylococcal food-borne disease (SFD) is one of the most common food-borne diseases worldwide resulting from the contamination of food by preformed S. aureus enterotoxins." (Kadariya *et al*. 2014). The application of stainless steel is very important because the material does not affect the food ingredients that are being produced. In the result, we need a product development in the process of separating soybean skin so that contact with human skin can be reduced by stainless steel and hygienic standards can be improved.

Cycle time is the main factor in reducing the touch of human skin from the production of tempe. Turpin describe about cycle time: "The workstation cycle time is the average time between successive units of output at workstation i. That is, how fast the workstation can produce another unit, on average." (Turpin, 2018). the cycle time using hands in tempe production is 115.7 minutes. After calculating the cycle time in a wet area with 3 work areas, namely the skin separation area, shoot separation area, and stirring area, it was found that the skin separation area is a work area that has the largest cycle time of 45.59 minutes for a production cycle. While the shoot separation area has a cycle time of 21.23 minutes with four working elements and the stirring area has a cycle time of 43.62 minutes. Of the three processes, an operator needs a break in accordance with their needs. With this cycle times, the amount of water consumption and the cost of electricity for tempe production is 1,836.9 liters and 47,659 IDR/ month.

In the process of skin separation, cycle time is the biggest factor, so it takes cycle time efficiency in this process. The purpose of this study is to reduce the cycle time of the production process with human hands by developing a production tool through an analysis of the elements of work. According to these problems, the suitable method to solve the problems is reverse engineering. Reverse engineering is a method to create new product according to the existing equipment and customer needs. Reddy mention about reverse engineering: "Reverse engineering is the general name of digital technology of CAD model, reconstruction technology of geometric model and manufacturing technology, which is different from the creation of traditional geometric model." (Reddy *et al*. 2016). Reverse engineering method is one method to develop products especially to redesign a product with consideration of user. In this study, new product designs were produced from morphological tables selected by concept scoring and screening so as to produce a design that has a lower work risk value than the existing process.

Based on the explanation above, this research will be conducted using the reverse engineering method with the interview stage to determine the user needs and the best concept selection will be done with the concept of

scoring and screening. The reverse engineering method conducted for existing products to develop a new soybean peel separator container to eliminate the skin contact of human.

Methods

1. Reverse engineering. "Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering." (Raja, 2008). Sinha also has a broad understanding of reverse engineering when he mentions: "Reverse engineering in its complete definition refers to the process of create a completely engineered prototype, a clone in form and function, from a physical part." (Sinha *et al*. 1996). In another perspective, Page said: "This form of RE is also a systems level approach where an engineer disassembles the item of interest to develop an understanding of the functional relationship of components or to gain insight into the types of materials used to fabricate the components." (Page *et al*. 1996). Alai describe also an importance of reverse engineering: "Reverse engineering plays an important role is surface re-modeling. It is driving research in the 21st century and encouraging multidisciplinary collaboration." (Alai, 2013)

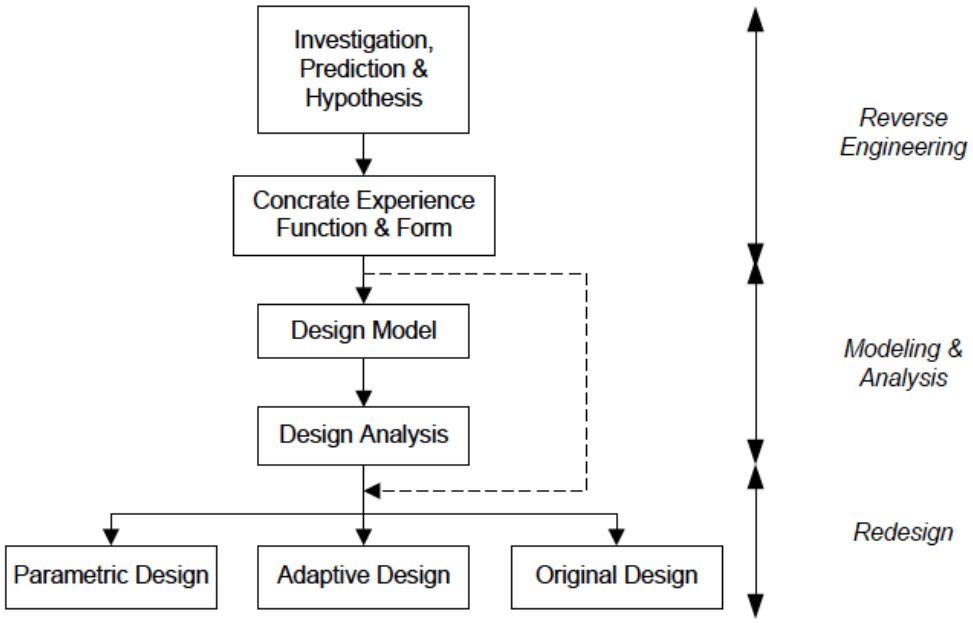

Figure 2 Reverse engineering and redesign methodology according to Otto and Wood (1998)

According to the steps and flow of reverse engineering, Otto and Wood describe: "Reverse engineering detailed in three phases compose the overall structure of the methodology: reverse engineering, modelling and analysis, and redesign. The first stage of reverse engineering begins with investigation, prediction, and hypothesis of a product being redesigned. Through this approach, the product is treated, figuratively and literally, as a black box to avoid bias and psychological inertia. Customer needs and market analyses initiate the effort. After systematic prediction of the functions and principles that solve these needs, the reverse engineering phase ends with product disassembly and experimentation, wherein the product under study is dissected to understand its actual function and form. Design modelling and analysis follows reverse engineering. The intent in this phase is to fully understand the physical principles and design parameters for the product. Redesign completes the methodology with a choice of three avenues for product improvement: parametric, adaptive, and original." (Otto & Wood, 2001)

2. Concept selection. Kusnayat describe the importance of weight for select the concept: "The determination of the percentage of relative weight makes it easier to choose concept based on their importance more systematic."

(Kusnayat *et al*. 2018). Concept selection is a method to choose one of the best concept. Each concept produced from reverse engineering method. The amount of concepts are unlimited, depends on the customer needs and morphological chart. Hadid mention about concept selection: "Product modelling in the form of virtual and physical will produce deep insight into operations and possible improvements that can be achieved parametrically. At this stage the results from selected concepts will be developed according to the target technical specifications." (Hadid *et al*. 2017).

Experiments

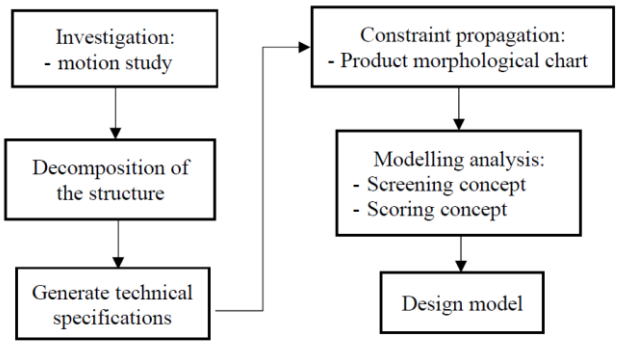

Figure 3 Stages of experiment

Step 1: Investigation, Prediction, and hypothesis. The process of separating soybean peel is a process found in a wet area. This process uses an operator who works for 45.59 minutes for each production cycle (60 kg). The capacity of the container in this process is 60 kg and is carried out by one operator.

Use of the past product: The operator stirs the soybeans by reaching the deepest peel of the soybean by using a sieve and pulling it upwards. After that, the operator rotates the soybeans by placing a sieve on the surface of the water and rotates it in a horizontal direction which makes the peel of soybeans rise to the surface. After the soybean peel rises to the surface, the operator will catch the skin on the surface by directing the sieve and moving the sieve to follow the movement of water at the same time. Soybean peel will be caught by the sieve, while the water will fall back into the container due to the small cavities in the sieve. After the sieve is fully filled with the skin of the soybean, the operator removes the skin into the skin disposal container. Sieve images and soybean skin separation mechanism can be seen in Figure 4.

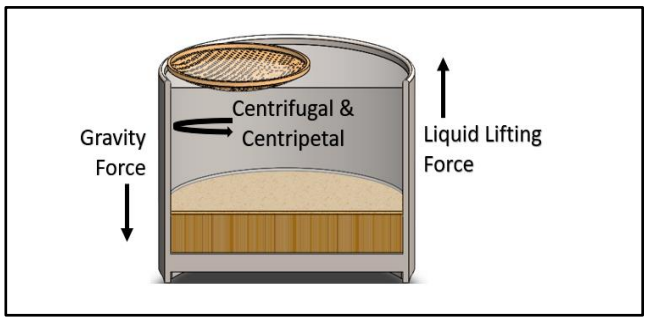

Figure 4 The mechanism of the soybean peeling process. There are three mechanical forces such as gravity force, centrifugal and centripetal force and liquid lifting forces are involved in the process.

Motion study: Time and motion study is a business efficiency method that has been generally used to develop and advance a work system. (Payne *et al*. 2006). This study was conducted to determine each movement and

force which occurs in a workstation. Result of this studies can be used as a reference to create elements of developed machine. Time study requires a direct and constant observation of a job or task to measure the time engaged to complete a task using a stopwatch. (Kim, 2017). The basic movements used in the process of separating soybean peel are in Table 1.

Table 1 Work elements on peel separating process

Therblig name	Therblig code	Therblig symbol
Reach	RE	
Use	U	U
Position	P	
Release load	RL	

Step 2: Decomposition of the structure. Structure decomposition analysis is done to find out the detail of each part in the product to be developed. The practical usefulness of the model obtained at the end of the RE process depends on multiple factors, the most important being the ability to recover the intrinsic design intent defining the part (Bounamici, *et al*, 2018). By conducting an in-depth analysis of each part of the product, the development of soybean peel separator containers can be more easily done. The structure of peel separating equipment can be seen on Figure 4.

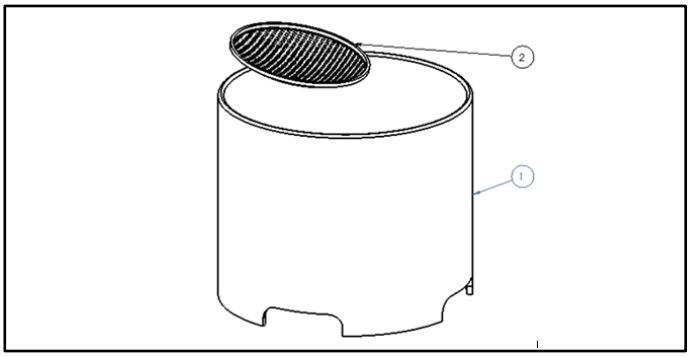

Figure 5 Components of peel separating equipment. The equipment contain two components; sieve and container.

Decomposition analysis: The sieve, used by the operator to stir the soybeans so that all soybeans can be separated from the skin. This tool also functions to rotate the water so that the peel of soybeans can rise to the surface of the water. The screen is rotated by the operator with a standard rotation speed of 60 rpm. In addition, sieves also function to filter the peel of soybeans so that water is not wasted.

Soybean container serves to accommodate soybeans and water which is used to separate the soybeans. This container has a diameter of 60 cm with a storage capacity of 60 kg of soybeans. Step 4: Establish technical specifications. Technical specifications is next to in-depth analysis of existing products.Ulirich mention this step to determining the product objective: “Technical specification is an objective of the developer team, it can described to make succesive in the market.” (Ulrich and Eppinger, 2000). This process includes the establishment of specifications, benchmarking, and the selection of new product concepts. Making this technical specification can determine the existing variables into quantitative product targets. This variable change will facilitate the product development process that will be carried out.

Determine technical characteristics: After obtaining the characteristics of the product attribute, an analysis of the product attributes will be carried out so that technical characteristics appear. Each product attribute can bring up 1 or more technical characteristics that depend on technical needs in the development of the soybean peel

separation container. The results of determining the technical characteristics of product attributes are shown in Table 2.

Table 2 Product attribute and technical characteristics of peel separation container

Product attribute	Technical characteristics
Source of power	Amount of force needed
	Number of rotations of water in 1 minute
Soybean stirrer and turner	Blade diameter
	blade length
The driving mechanism for water to the surface	The amount of thrust needed
	Time to clean soybeans
Discharge of soybean peel	Wide drainage flow of soybean peel
	High drainage rate of soybean peel
Soybean sweeper	Sweeper strands length

Determining targets to be achieved for technical characteristics: This stage is carried out to determine the characteristics so that the target specifications of soybean husk separator containers can be known. The target of each technical characteristic can be seen in Table 3.

Table 3 Target and technical characteristics of peel separation container

Technical characteristics	Target	Unit
Amount of force needed	1	HP
Number of rotations of water in 1 minute	60	rpm
Blade diameter	16.5	cm
Blade length	58.5	cm
The amount of power needed	220	Watt
Time to clean soybeans	< 115	minutes
Wide drainage flow of soybean peel	5	cm
High drainage rate of soybean peel	5	cm
Sweeper strands length	25	cm

Step 5: Constraints propagation. Benchmarking is the study of existing products and has similarities with the products being developed (Ulrich & Eppinger, 2000). By using this analysis, similar concepts that will emerge can facilitate the design of physical concepts from soybean peel separator containers.

Product morphological chart: In the product morphological chart, there are many choices that is the initial thought of the product development plan. The choice of initial thinking about product development is then combined to bring out a systematic solution. Product morphological chart in this study can be seen in Table 4.

Table 4 Product morphological chart

Function	Alternative		
	1	2	3
Source of power	Electric motor 1 HP	Electric motor 5 HP	-
Soybean mixer	Horizontal flat blade	Vertical flat blade	High speed blade
The mechanism of pushing water to the surface	Water pump	Compressor	-
Discharge of soybean peel	Disposal path	Disposal hose	-
Skin sweeper	Metal wire	Nylon wire	-

From the morphological chart results showed that the concept to be developed has a number of possible combinations, namely 2x3x2x2x2 = 48. Analysis of 48 concepts in a comprehensive manner will cause difficulties and ineffectiveness of the research process. Then it is necessary to eliminate alternatives that are deemed inappropriate with the existing conditions and difficult to realize. After that, an alternative concept based on the results of elimination is made, which can be seen in Table 5.

Table 5 Product morphological chart after eliminating the option

Function	Alternative	
	1	2
Source of power	Electric motor 1 HP	-
Soybean mixer	Horizontal flat blade	Vertical flat blade
The mechanism of pushing water to the surface	Water pump	-
Discharge of soybean peel	Disposal path	Disposal hose
Skin sweeper	Nylon wire	-

The reasons for eliminating other alternatives is the market availability and power efficiency. Using 5 HP motor will increase the use of electricity and too much energy will be produced. In the pushing mechanism, the use of compressor is eliminated. Compressor is not suitable with the layout of production floor and not in accordance with hygiene standards of tempe industries, likewise the use of nylon wire.

After obtaining a combination of results from the elimination process, an alternative combination of functions is possible to be combined with other alternative functions and also obtained alternatives that have a large possibility of realization. The results of elimination are obtained by changing the number of concept combinations, namely 1x2x1x2x1 = 4 combinations.

Step 6: Modeling analysis. The purpose of this concept screening and scoring is to narrow the number of concepts quickly and to improve concepts (Ulrich et al. 2000). Modeling analysis can help the designer to chose the best concept that was made. Concept evaluation is based on the criteria of each combination which means that also based on the customer or user needs. The process will be combined to create a systematic solution (Kusnayat et al. 2018). The concept assessed by comparing and assessing each concept with the reference concept (D). The screening concept process is shown in Table 6. If comparative concept is better than reference concept, the value is plus (+). Then if the comparative concept is equal with reference concept, the value is zero (0) and if the comparative concept is worse than reference concept, the value is minus (-).

Table 6 Screening concept

	Concepts			
Selection Criteria	A	B	C	D
Source of power	0	0	0	0
Soybean mixer	-	-	0	0
The mechanism of pushing water to the surface	-	-	0	0
Discharge of soybean peel	0	0	0	0
Skin sweeper	+	0	+	0
Source of power	0	0	0	0
Sum + 's	1	0	1	0
Sum 0's	3	4	5	6
Sum -'s	2	2	0	0
Net Score	-1	-2	1	0
Rank	3	4	1	2
Continue?	yes	no	yes	yes

After the concept screening was done, three concepts were selected based on the assessment based on the criteria set. The concepts chosen to enter the concept scoring process are concepts A, C, and D. Scoring concept is the methods to choose one of the best concept. Before doing this stage, researchers spread questionnaire form to the workers and marketing department in tempe industries. The questionnaire contain five points of selection criteria. The respondents scoring each points from 1 to 5. Each points assessed based on the value of importance and the value of satisfaction. The value of importance changed into a percentage which means weight, while the value of satisfaction will changed into rating value. The results of the concept scoring process is shown in Table 7.

Table 7 Scoring concept

Selection Criteria	Weight	Concept					
		A		C		D	
		Rating	Score	Rating	Score	Rating	Score
Source of power	0,16	4	0,63	4	0,63	4	0,63
Soybean mixer	0,21	2	0,42	4	0,84	4	0,84
The mechanism of pushing water to the surface	0,16	2	0,32	3	0,47	3	0,47
Discharge of soybean peel	0,11	4	0,42	4	0,42	4	0,42
Skin sweeper	0,16	4	0,63	4	0,63	2	0,32
Total Score		3,26		3,84		3,53	
Rank		3		1		2	
Develop?		No		Yes		No	

Result of scoring concept is the selection of the best concept. Concept C is choosen as a concept to be further developed.

Step 7: Design model. The components of finally selected concept was identified after the selection process. The following is an explanation of the design concept for each component. The design model obtained from the concept selection results is shown in Figure 6.

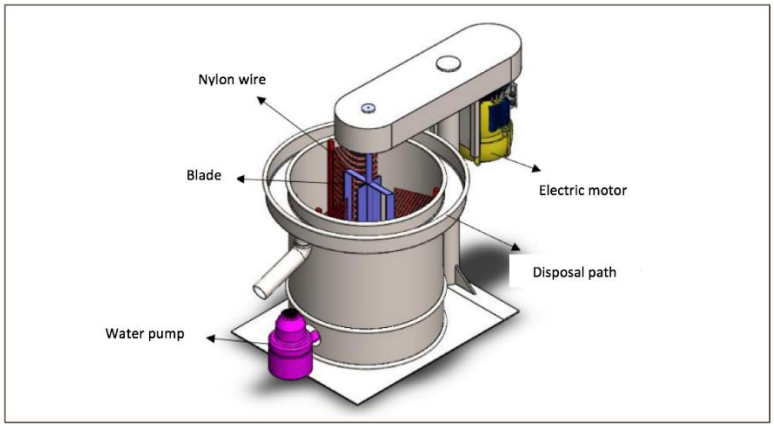

Figure 6 Peel separating process using hand-touching, operator touch the soybean directly

Step 8: Prototyping and testing. Several separate and similar prototypes can be used, one of which is to describe how the product is produced, while the other is to describe how the product works (Ulrich *et al*. 2000). At this stage a prototype was made based on the concept of the selected design. The prototype was made by standardizing the use of tools in Rumah Tempe Indonesia, Bogor. The criterion for this test is the calculation of cycle time of the developed skin separator.

Result and discussion

Soybean peel separator container is developed to have an electric motor that can replace the operator's energy so that the process of separating soybean peel does not fully use energy from the operator. Rounds per minute (rpm) from the optimal stirrer rate was 60 rpm. When the stirrer rotates beyond 60 rpm, the skin and soybeans will rise together thus the beans will be wasted through the drain. A motor (1 HP) is used to provide the mechanical energy for the rotation of the container and a pump (220 W) is used to push soybeans and skin to the surface.. In addition, the time to separate the peel from the developed concept was faster than the existing technique which is 70.77 minutes for one production cycle (60 kg) and reduced the cycle time by 39%. Comparison of the developed and existing concepts in the process of separating soybean peel can be seen in Table 8 and comparison of technical characteristics can be seen in table 9.

Table 8 Comparison the functions of existing and developed peel separator

Function	Existing	Developed
Source of power	Sieve	Electric motor
Soybean mixer	Sieve	Vertical flat blade
The mechanism of pushing water to the surface	-	Water pump
Discharge of soybean peel	-	Disposal path
Skin sweeper	Sieve	Nylon wire

Table 9 Comparison of technical characteristics of peel separators

Technical characteristics	Existing	Developed	Unit
Amount of force needed	-	1	HP
Number of rotations of water in 1 minute	60	60	rpm
Blade diameter	115	70,77	cm
Blade length	60	60	cm
The amount of power needed	-	220	Watt
Time to clean soybeans	-	5	minute
Wide drainage flow of soybean peel	-	5	cm
High drainage rate of soybean peel	-	25	cm

From the comparison of existing specifications and proposals, it can be concluded that there is an improvement in the process of separating soybean peel in processing time. Moreover there are two additional new features, the thrust force that sourced from the bottom of the container will accelerate the movement of the soybean peel and the addition of a drainage pathway for the peel of the soybeans that has been separated from soybeans. The specification of the proposed design has decreased the cycle time by 39% so that the new design could reduce the output time of the peeling process. The cycle time decreased because of the skin separated and wasted trough disposal path at the same time.

The time saving of the peeling process due to the new design minimize the water and electricity use. Using the developed skin separator from soybean, a decrease in water use volume was 42%. Reduction of water volume is caused by a water pump which functions to recycle water to return to the initial separation process, so that water is not wasted. Recap comparison of cycle times and water usage.

Table 10 Comparison of cycle time and water use for existing and new design.

Criteria	Unit	Existing	Developed	Reduction
Cycle time	minute	115,77	70,77	39%
Use of water	Liter	1.836,90	1.072,05	42%

Conclusion

The new design of soybean peel separator container can decreasing 39% of cycle time in tempe production, which mean also decreasing the time of the manual worker. This separator container can reduce the hand-touch of workers. The quality and cleanliness of soybean will be maintained. Reduced cycle time also have an effect to minimazed the use of water and electricity.

Acknowledgement

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