

Chapter 2

Conceptual Design Development

2.1 Introduction

In the modern design, conceptual design is an important activity in the design process, it is constantly being emphasized that incorrect conceptual design may lead to expansive rework and problem that may happen after the product is fabricated. According to Pugh (1991), conceptual design activity is an activity for generating design solution and evaluating them to satisfy the PDS. Conceptual design with NFC is normally different from metals because in composites, many design features are different and the tailor-made nature of composites has made the design approach to be different as well. Conceptual design with NFC is similar to design with conventional composite product. This activity requires several steps such as design brief, information gathering and market investigation, and development of product design specification (PDS). This is called ‘pre-conceptual design’ by Sapuan (2017).

Sapuan and Mansor (2016) have used Pugh’s approach in conceptual design of NFC products. In their work a case study of conceptual design of NFC lap top case embedded with external cooling fan was performed. The major tool used was Theory of Inventive Problem Solving (TRIZ). The use of different design tools and techniques are emphasized the recent work on conceptual design of NFC. Tools like analytic hierarchy process (AHP), function analysis diagram, failure mode and effect analysis (FMEA), TRIZ, and Morphological chart among existing tools in the conceptual design of natural fiber reinforced composite products. Mastura (2017) has used different techniques to perform conceptual design of NFC product, i.e. an automotive anti-roll bar. Mastura (2017) reported the use of existing tool in business i.e. blue ocean strategy (BOS) as a new tool of conceptual design of NFC. In her study, conceptual design of automotive anti roll bar from hybrid glass-natural fiber reinforced thermoplastic composites was carried out. She introduced BOS tools such as the four actions frame-work (the eliminate-reduce-raise-create grid) and the

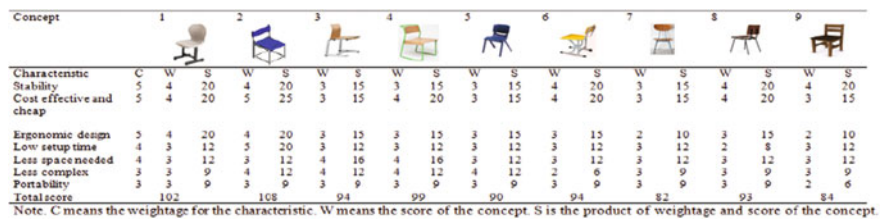


Fig. 2.1 Matrix evaluation of NFC chair (Mahmood et al. 2016)

strategy canvass (value curve) in coming up with different concepts of automotive antiroll bar from natural fiber-glass reinforced polymer hybrid composites.

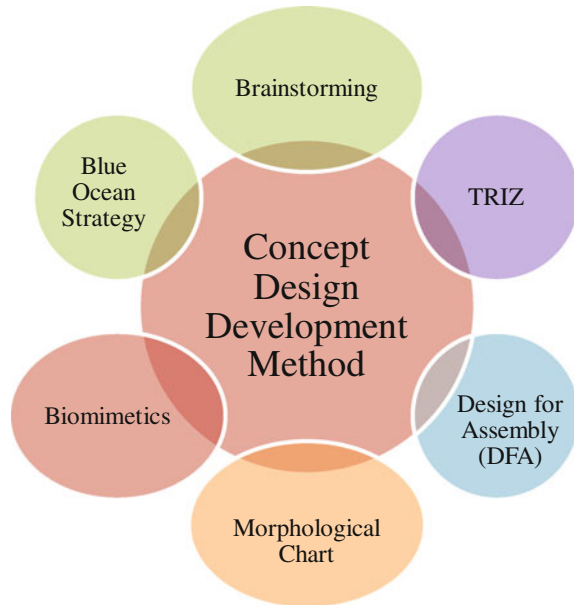
Mansor et al. (2016) reported on the conceptual design development of green biocomposites product using bicycle frame as the case study. The TRIZ method was utilized to produce new conceptual design of the bicycle frame, which can be produced using NFC to replace the use of steel based bicycle frame. The TRIZ 40 engineering contradiction tool was used to model the problem, while the contradiction matrix and 40 inventive principle tools were used to generate the idea for the design solution. By using the innovative design tool, the current NFC material limitation which is the low strength can be address through geometrical design solution such as using ribs and triangulation to increase the frame structural strength. In another report, Mansor et al. (2015a, b) also demonstrate the use of integrated TRIZ and Morphological chart method in generating new conceptual design of automotive rear spoiler component, using kenaf composites. Similar TRIZ tools such as engineering contradiction, contradiction matrix and 40 inventive principle were used to formulate the design solutions based on the kenaf composites structural strength limitation. Similar integrated TRIZ-Morphological chart method was also used to generate new conceptual designs of automotive parking brake lever component based on kenaf fiber polymer composites (Mansor et al. 2014).

Mahmood et al. (2016), Yusof et al. (2016) and Shaharuzaman et al. (2016) also performed conceptual design studies of NFC using similar approach adopted by Mastura (2017) for the chair (Fig. 2.1) and table, automotive crash box and automotive door panel.

2.2 Conceptual Design Development Methods

The purpose of conceptual design in NFC product development is to create the initial shape or form of the end product. Conceptual design are also the quickest way to visualize the product solution especially to customers. Most often, several conceptual design are produced based on the given product design specifications.

Fig. 2.2 Example of concurrent engineering methods for NFC product conceptual design and idea generation



The finalized concept design will later be applied for the next product development stages, which are detail design and product manufacturing. In this stage, concurrent design methods are most widely applied to help designer in completing the product design process (Sapuan and Mansor 2014). Figure 2.2 shows some of the concurrent engineering methods which can be applied to generate idea for NFC products.

One of simplest method for conceptual design development is the brainstorming method. The brainstorming process is best performed by group discussions, with the presence of an instructor to help the discussion process be managed in a systematic and structured manner (Sutton and Hargadon 1996). The brainstorming process can be engaged effectively by always relating the produced idea to the project goal, illustrating the idea such as through sketching, selecting and elaborating the idea which are promising, creating connections between the generated idea (or concepts) and combining them to produce more innovative ideas (or concepts).

The other method for conceptual design development is called “Teoriya Resheniya Izobretatelskikh Zadatch” (TRIZ) in Russian which also termed as Theory of Inventive Problem Solving in English. Establish since the 1940s by a Russian patent officer named G. Altshuller in 1940s, the method was created based on the concept of obtaining ideality for the solution. The ideality concept rejected the conventional idea of having to accept compromise or trade-off in the design solution. There are many tools within the TRIZ method, based on how the problem is modeled. Among the solution generation tools available in TRIZ contradiction matrix, 40 inventive principles, 76 standard solutions and ARIZ (San et al. 2009).

Another powerful tool within the TRIZ method is the trends of evolution in engineering system (TESE). The tool outline the technological growth toward achieving solution ideality, which can benefits in producing ideas which can overleap current design situation (Yu and Fan 2012).

Furthermore, additional method for NFC conceptual design is Design for Assembly (DFA). The method stem on the idea of generating design solutions which be easily assembled, such as solutions that contains less components, which later will contribute to reducing the assembly time and the assembly cost. This can be made combining parts which have the same function, or adding multifunction attribute to a singular parts. In addition, the idea generation can also include the consideration of creating design features which help to ease the assembly process, such as ease of handling through proper component orientation, grip shape and insertion mechanism (Boothroyd 1994).

The next available method is the Morphological chart. The Morphological chart is a visual way to show the product functionality and find the alternative means and combination to achieve the desired functionality. A matrix is form using the Morphological chart method, which consists of the product components and its function. The central idea to the method is to explore potential alternative design attributes to meet the required function, and later combined all the identified functional design attributes to generate final conceptual designs for the product. Despite is simplicity, the method can yield vast number of idea just by combining the different function alternative together. In addition, the graphical feature incorporated within the method can also help designer to visualize clearly the potential solutions in hand (Silvester et al. 2013).

Blue Ocean Strategy (BOS) is also one of the method which can be used to generate ideas and conceptual design for NFC product. Although BOS is created initially for strategic planning and management purpose in order to gain uncontested market space and make the competition irrelevant, the framework within it can suit nicely with the requirement is product designs. One of the tool within the BOS framework is to find solution based on four (4) main action, which are to find ways in raising the current product in term of its quality and productivity, eliminating and reducing existing non-value added features, and create new features which add more functionality and values to the existing product. Mastura et al. (2017a, b, c) demonstrated the use of BOS in developing new conceptual design of automotive anti-roll bar, using hybrid NFC as the raw material to replace to use of steel.

Another innovative approach in concept generation for NFC products is using biomimetics or biomimicry concept. The biomimetics concept was inspired by nature, whereby inspiration and idea generation were developed by imitating the nature's element and adopting the elements into design features (Benyus 1997). One of the famous example of the biomimetics method is the design of flying contraption by Leonardo da Vinci which was adopted from bat wings. There are several procedures in the biomimetic concept design application which are problem definition, reframing the problem, search for appropriate biological solution, defining the identified biological solution and finally extraction the biological

principle into design ideas (Helms et al. 2009). In the case of composites application, the biomimetics concept was successfully applied to the design of new double helical structure for composite laminates, based on the idea from bamboo bast fiber structure (Li et al. 1995) and to the design of new composites sandwich panels based on the idea from cross-sectional feature of lily plant leaf (Easterling 1990). Moreover, the biomimetics adoption based on the growth of wood branch-trunk joint for new bio-inspired composites T-joint was also reported which able to increase the bending failure initiation load and elastic strain energy capacity compared to conventional base-line T-joint design without jeopardizing the composites stiffness, weight and cost (Burns et al. 2012).

2.3 Case Study on Conceptual Design Development of Natural Fiber Composite Products Using TRIZ-Morphological Chart Method

In this section, a case study focusing on ironing board product was selected to demonstrate the application of conceptual design development of NFC products. The case study is explained through several product design stages, which encompass design brief, defining the project problem statement, modeling the design problem, generating idea as the product solution and finally developing the final conceptual design solution. The overall ironing board product design development process was completed using the integration of TRIZ and Morphological chart method.

2.3.1 Design Brief

In most design cases, the designer received a set of guidelines or design brief after performing a series of discussions with customer to solve the problem. In this case study, a design brief was given to design a new consumer ironing board which utilized NFC or green-composites as the material to form the ironing board legs as shown in Fig. 2.3.

The design intent is to create an eco-friendly consumer product by replacing current steel based-ironing board legs with green composites based-legs so that the new product will able to be easily handled due to the reduced weight, as well as deliver lower product cost. In addition, the customer also expect that by introducing more renewable and environmental friendly materials to the product, it will also appeal to higher consumer acceptance in line with current growing awareness in environmental sustainability by consumers. Based on market research by the customer, the market demand for eco-friendly ironing board is expected to escalate up to 50,000 units per month within 6 months. In addition, the new eco-friendly

Fig. 2.3 Example of ironing board product with iron rest



Table 2.1 Product design specifications for eco-friendly ironing board

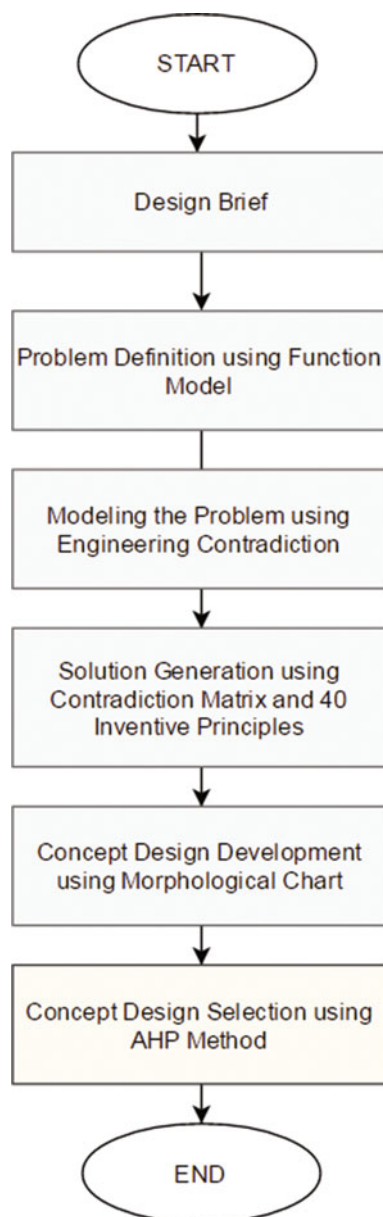
Product design specifications
• 135 × 45 cm, Solid steam iron rest • Able to support moderate external load • Long life and durable • Production target 50,000 units a month within 6 months • Lightweight and low cost • Recyclable • Leg components made from NFC. Other components remain to use existing type of material

product will also be subjected to pre-production models development and testing by engineering department. Table 2.1 summarized the overall product design specifications (PDS) for the eco-friendly ironing board product.

Analyzing the aforementioned situation, the designer is faced with contradicting requirement and has to balance between gaining ease of operation by the user without compromising the structural strength and reliability of the product. Most often, designer opted on the “trade-off” decision to solve the problem, such as having the need to use bigger leg component size or increase the number of legs components in order to withstand the load but in the same time scarifying the initial weight reduction advantage of the NFC. To solve the given problem, TRIZ method was selected to solve the problem. TRIZ method is utilized for the idea generation and concept development process for the new eco-friendly ironing board. As discussed in the previous section, the TRIZ method was found capable of guiding designers in the innovative problem solving process to meet the product design specifications based on customer requirements. In addition, the morphological chart is also employed alongside the TRIZ method in developing new conceptual designs

of the product. Later, the AHP method was applied to select the best conceptual designs among the developed alternatives which able to satisfy all the multiple criteria as required by the customer. The overall design methodology applied for this case study is shown in Fig. 2.4. Details of the conceptual design development and selection process for the eco-friendly ironing board product are explained in the following sections.

Fig. 2.4 Overall concept design development and selection framework



2.3.2 Problem Definition

Based on the design brief, the goal of the project was to create a new design of eco-friendly ironing board by substitute the use of steel with NFC material to construct the leg components of the product. The designer acknowledged that the proposed NFC material will able to deliver the customer expectation of producing lighter ironing board product for ease of operation by the consumers due to the lower density material property of the NFC materials compared to steel. Moreover, the use of renewable, recyclable and low cost plant based fibers in the NFC to construct the leg components of the product will also be able to lower the product cost and reduced the environmental effect of the product materials compared to the existing steel based component. However, the introduction of NFC to construct the leg components also created problems in term of the structural strength, whereby the NFC has lower mechanical strength property compared to steel, thus may jeopardize the functional performance of the whole product to withstand the load during ironing operation by consumer. The reliability performance of the legs to hold the load during longer ironing process will also reduce due to the same limitation in mechanical strength of the NFC material.

The problem identification process using TRIZ is started by modeling the problem using function analysis method. The objective of the function analysis is to map and analyze the interaction performance between the product (engineering system) with its subcomponent (subsystem) and its environment (supersystem). The interactions can be classified as useful function, useful but insufficient, useful but excessive and harmful function. Through the function model created, the actual root cause of the problem for the product can be identified and verified, thus enabling more precise solution to be developed which able to solve the contradiction occurred. For this case study, the function model of the ironing board product (engineering system) is formulated as shown in Fig. 2.5.

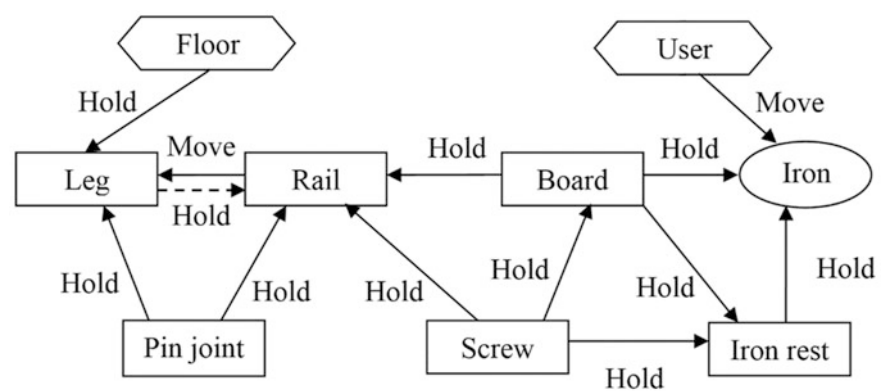


Fig. 2.5 Function model of iron board product

As observed in Fig. 2.5, the ironing board product consists of six (6) subsystems which are the legs, rail, board, pin joint, screws and iron rest. The iron rest component acts as the holding place for the iron while not in use, and is attached to the board. The board is also attached with the rail, which enable adjustment of the leg height for consumer during the ironing process. The legs component holds the upper portion of the ironing board and connected to the rail. There are also two mechanical connections involved in the whole product assembly, which are pin joint and the screws. The pin joint is mounted on the center of the legs to enable them to be folded, while the screws holds the rail to the board and the iron rest to the board. In addition, the supersystem involved are the floor and the user, whereby both of the supersystem elements also can give effect to the operation of the engineering system. Based on the eco-friendly ironing board product, the function model is shown to have one insufficient interaction between the legs and the rail. By using NFC material to construct the legs component, the capability of the structure to hold the ironing board upper components (rail, board and iron rest) is reduced due to the inherent low mechanical strength of the materials as compared to existing steel-based legs, making the performance of the leg components insufficient to function as higher load is exerted on the product. Thus, the function model identified the root cause of the problem as well as verified the initial assumption of the contradiction which will occurred by using NFC material to construct the ironing board legs.

2.3.3 *Modeling the Problem*

The new eco-friendly ironing board product will be successful if the root cause of the problem (which is the legs produced using NFC material) can be solve. Using TRIZ, the contradicting problem of wanting to increase the ease of operation for users while maintaining structural strength and operation reliability of the product can be resolve using several modeling method, such as engineering contradiction, physical contradiction and substance field model. For this case study, the problem is modelled using engineering contraction method, whereby within a same situation, several improving and worsening engineering parameters are present. Kim and Cochran (2000) defined engineering contradictions as condition whereby improvement of one technical aspect of the system caused deterioration of other parameters in the same system. TRIZ strived to solve the contradiction without having to opt for trade-off decision, so that the desired improving engineering parameters can be achieved and the worsening engineering parameter can be eliminated concurrently.

The engineering contradiction problem model is stated using the general statement of “If parameter x is present, then parameter y improves but parameter z worsens”. The intention of formulating the engineering contradiction statement is to help designer to understand clearly the current situation and what parameters are contradicting each other in the same situation (San et al. 2009). Thus, for the

eco-friendly ironing board design problem, the resulting engineering contradiction statement are formulated as follows:

IF using low weight natural fiber composites (NFC) to fabricate the ironing board legs,
THEN easy to carry/operate the product by the user, BUT caused lower structural strength capability to the legs to handle the load given during ironing process.

Alternatively, the loss of structural strength due to the use of NFC materials can also be reflected in the loss of operation reliability, whereby although the new product able to operate at moderate load for short term operation, but is not reliable for long term use by the user. Thus, another engineering contradiction statement can be formulated to represent the contradiction as follows:

IF using low weight natural fiber composites (NFC) to fabricate the ironing board legs,
THEN easy to carry/operate the product by the user, BUT caused degradation of the product performance to function in longer ironing process time.

Based on both engineering contradiction statements above, it can be concluded that based on TRIZ problem model method, the same technical improvement required may cause more than one worsening technical parameters to be involved simultaneously.

2.3.4 Idea Generation for Solution

One of the difficulty faced in creative problem solving is to break the psychological inertia (overcoming the problem of thinking outside of the box and clarity of thought) in order to find the required solution (Ilevbare et al. 2013). Using TRIZ method, the psychological inertia can be overcome by converting high level technical jargons and/or complicated technical term into equivalent simpler general term (Kremer et al. 2012). TRIZ listed a set of 39 system parameters which able to represent generalized definition of all the technical terms as shown in Table 2.2.

Thus, the next step is to match the specific technical term as outline in the engineering contradiction statement to the most suitable 39 system parameters. Table 2.3 summarized the overall TRIZ system parameters selected to match the formulated engineering contradiction statements in this case study.

Stage 3: Identification of General Solutions using TRIZ Contradiction Matrix

The next step towards generating solution to solve the contradiction is by using the TRIZ contradiction matrix. The contradiction matrix is a 39×39 matrix table which mapped all the 39 system parameter according to the improving system parameters and worsening system parameters on the left and top column, respectively. Inside the matrix, a list of general solutions are stated which represent another TRIZ tools which is the 40 Inventive Principles. Table 2.4 shows an example of the TRIZ contradiction matrix.

Table 2.2 TRIZ 39 system parameters

#1—Weight of Moving Object	#21—Power
#2—Weight of Stationary Object	#22—Loss of Energy
#3—Length (or Angle) of Moving Object	#23—Loss of Substance
#4—Length (or Angle) of Stationary Object	#24—Loss of Information
#5—Area of Moving Object	#25—Loss of Time
#6—Area of Stationary Object	#26—Quantity of Substance
#7—Volume of Moving Object	#27—Reliability (Robustness)
#8—Volume of Stationary Object	#28—Measurement Accuracy
#9—Speed	#29—Manufacturing Precision (Consistency)
#10—Force (a.k.a. Torque)	#30—Object Affected Harmful Factors
#11—Stress/Pressure	#31—Object Generated Harmful Factors
#12—Shape	#32—Ease of Manufacture (Manufacturability)
#13—Stability of the Object's Composition	#33—Ease of Operation (Manufacturability)
#14—Strength	#34—Ease of Repair
#15—Duration of Action of Moving Object	#35—Adaptability or Versatility
#16—Duration of Action of Stationary Object	#36—Device Complexity
#17—Temperature	#37—Difficulty of Detecting and Measuring
#18—Illumination Intensity	#38—Extent of Automation
#19—Use of Energy by Moving Object	#39—Productivity
#20—Use of Energy by Stationary Object	

Table 2.3 Mapping specific requirements with TRIZ 39 system parameters

Specific requirement	TRIZ 39 system parameters
<i>Improving feature targeted the new design</i>	
• Ease to carry the product by using lightweight material to construct the leg components	#33-Ease of operation
<i>Worsening feature expected for the new design</i>	
• Lower structural strength to handle the load given during ironing process	#14-strength
• Degradation of the product performance to function in longer ironing process time	#27-Reliability

The TRIZ inventive principles are a set of solution principles found by Altshuller through his studies on patent. Through his examination, he found that innovative patents showed the use of repeating solution principles to solve the problem. He documented the findings and arrived to the conclusion of 40 types commonly used solution principles across the patent (Li 2010). He later named the principle in general term such as segmentation, taking out and local quality to assist

Table 2.4 Example of TRIZ contradiction matrix (San et al. 2009)

	Worsening System Parameter  Improving System Parameter 	Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Area of moving object
		1	2	3	4	5
1	Weight of moving object		-	15, 8, 29, 34	-	29, 17, 38, 34
2	Weight of stationary object	-	40 Inventive Principles		10, 1, 29, 35	-
3	Length of moving object	8, 15, 29, 34			-	15, 17, 4
4	Length of stationary object	-	35, 28, 40, 29	-		-
5	Area of moving object	2, 17, 29, 4	-	14, 15, 18, 4	-	

users in understanding the meaning of the inventive principles. Table 2.5 lists of the TRIZ 40 inventive principles derived from Altshuller study.

After identifying the improving and worsening parameters involved in the engineering contradiction statement, the user can refer to the contradiction matrix to determine the recommended inventive principles which can be used to generate ideas to solve the engineering problem. For example, based on Table 2.5 inventive principles number 15 (Dynamics), 17 (Another dimension) and 4 (Asymmetry) can be applied to solve the contradiction of wanting to improve the length of moving object while in the same time eliminating the problem related to area of the moving object. The contradiction matrix is a very simple and useful tool to assist users to quickly identify potential solution to solve the contradicting problem (Sheu and Lee 2011). It is also observed, that some of the cell inside the contradiction matrix do not have any recommended inventive principles listed in it. TRIZ explained that the empty cells do not represented that the problem cannot be solve, but instead represent the meaning that no particular set of improving or worsening parameters was encountered during Altshuller patent study. Thus, TRIZ recommended that all the 40 inventive principles are to be reviewed by the users to help find the solution for the problem. Similarly, the same process can be use by users to find solution in the case where the recommended principles as shown in the contradiction matrix unable to help users to find the relevant solution. Furthermore, users can apply one or more inventive principles to solve the same problem. Higher level of

Table 2.5 List of TRIZ 40 inventive principles (San et al. 2009)

1. Segmentation	21. Skipping/Hurrying
2. Taking out/Extraction	22. 'Blessing in Disguise'
3. Local Quality	23. Feedback
4. Asymmetry	24. Intermediary
5. Merging/Combination	25. Self- Service
6. Universality	26. Copying
7. "Nested Doll"	27. Cheap/Short Living Objects
8. Anti-weight/Counter-weight	28. Mechanics substitution/Another sense
9. Preliminary anti action/Prior counter-action	29. Pneumatics and hydraulics/Fluidity
10. Preliminary action/Prior action	30. Flexible shells and thin films/Thin and flexible
11. Beforehand cushioning/Prior cushioning	31. Porous Materials/Holes
12. Equi-potentiality/Remove tension	32. Color changes
13. 'The other way round'	33. Homogeneity
14. Spheroidality-Curvature	34. Discarding and recovering
15. Dynamics	35. Parameter changes
16. Partial or excessive actions	36. Phase transitions
17. Another dimension	37. Thermal expansion/Relative change
18. Mechanical Vibration	38. Strong oxidants/Enriched atmosphere
19. Periodic action	39. Inert atmosphere/Calm atmosphere
20. Continuity of useful action	40. Composite materials/Composite structures

inventiveness can be expected by combining more solution principles to solve the problem, which also able to provide multiple alternative of solution to the users based on the available resources.

For this case study, similar approach is used using the contradiction matrix. The improving parameter involved is ease of operation, while the worsening parameters related to it are strength and reliability. Table 2.6 summarized the mapping of the improving and worsening parameters as well as the recommended inventive principles involved in the eco-friendly ironing board problem.

As shown in Table 2.6, there are 8 inventive principles recommended from the contradiction matrix which could provide the solution for the ironing board problem. The next task is to analyzed each of the recommended principles and choose the appropriate principles to solve the problem. In many cases, especially for novice TRIZ users, the analyzing and selection process often created difficulty due to the overlapping and fuzzy definitions for the term used to represent the inventive principles (Cascini et al. 2011). Brief description for each of the inventive principles is also provided to users as guidelines when analyzing the information. Conversely, the fuzzy general solution terminology defined for the inventive principles can break the psychological inertia by providing broader thinking perspective to the

Table 2.6 Contradiction matrix for eco-friendly ironing board design

Improving parameter (feature to improve)	Worsening parameter	TRIZ 40 inventive principles
No. 32. Ease of operation	No. 14. Strength	No. 32. Colour changes No. 40. Composite materials No. 3. Local quality No. 28. Mechanics substitution
	No. 27. Reliability	No. 17. Another dimension No. 27. Cheap/Short Living Objects No. 8. Anti-weight/Counter-weight No. 40. Composite materials

user in exploring out-of-the-box ideas in based on similar principle (Luttrupp and Lagerstedt 2006).

2.3.5 *Generating Specific Solutions for the New Ironing Board Design*

In the final stage, ideas for specific solution strategies related to the general solution are developed. Based on the recommended general solution principles, only two principle were found able to provide relevant ideas to solve the problem. The two principles are local quality (no. 3) and composite materials (no. 40). For local quality inventive principle, among the specific solution which can be generated from it are by changing the existing circular shape of the ironing board leg from circular to rectangular shape, so that higher cross sectional area of the leg shape can be generated which consequently able to handle more compressive stress during operation. In addition, based on similar principle, the leg design can also be adjusted to incorporate structural ribs to enable higher stiffness for the component, and in the same time help to reduce the volume of the material required to achieve similar structural performance. Summary of the specific solution ideas based on the inventive principles for the new ironing board leg component are listed in Table 2.7.

2.3.6 *Developing New Conceptual Design for Ironing Board Design*

Based on Table 2.7, there are several parameters which can be changed from the current ironing board design to enable effective use of NFC material such as

Table 2.7 Solution Ideas for ironing board engineering contradiction based on TRIZ inventive principles

TRIZ general inventive principles	Solution descriptions	Specific solution idea
No. 3. Local quality	(a) Change an object’s structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform (b) Make each part of an object function in conditions most suitable for its operation (c) Make each part of an object fulfill a different and useful function	Change the uniform shape of the ironing board legs from uniform circular shape to non-uniform rectangular shape, U or I-shape for higher cross sectional area, thus increasing ability to handle more compressive stress during operation Change the side profile of the legs by adding supporting ribs to increase the stiffness of the structure Increase thickness at end joint section (more stress can be handle)
No. 40. Composite materials	(a) Change from uniform to composite (multiple) materials	Combine existing NFC material with synthetic fibers to form hybrid natural-synthetic fiber composites, which able to increase the structural strength, or Combine existing NFC material with stronger type of natural fibers to form hybrid NFC, which also able to increase the structural strength

changing the leg component cross section and adding ribs to stiffen the leg structure. The specific idea can be further exploded to identify other potential solutions by using Morphological chart method. The integration of TRIZ with Morphological chart method is able to increase the effectiveness of the TRIZ method by expanding the basic solution idea through graphical form, based on the component function. In this case study, the interpretation of the inventive principles conducted previously is further explored using Morphological chart as shown in Table 2.8. For example, the idea of using non-uniform cross section shape of the ironing board leg can be done through three possible ways, which are either using a rectangular shape profile, U-shape profile or I-shape profile.

Next, after identifying the possible variation for similar product function, the user can easily create many conceptual design ideas by combining individual solution idea for each design feature together. Expansion of ideas through the Morphological chart method also help designers to structurally explore other solution idea for similar function, thus enabling more creative ideas to be created in finding the optimal solution for the problem. For example, a new ironing board leg can be

Table 2.8 Morphological chart for the NFC ironing board leg design

TRIZ solution principle	Design feature	Solution		
		1	2	3
No. 3: Local Quality (i) Change the uniform shape of the ironing board legs from uniform circular shape to non-uniform rectangular shape, U or I-shape for higher cross sectional area, thus increasing ability to handle more compressive stress during operation (ii) Change the side profile of the legs by adding supporting ribs to increase the stiffness of the structure	Leg cross section profile	Rectangle	U-shape	I-shape
	Leg ribbing pattern	I	V	X
No. 40: Composite materials (i) Combine existing NFC material with synthetic fibers to form hybrid natural-synthetic fiber composites, which able to increase the structural strength, or combine existing NFC material with stronger type of natural fibers to form hybrid NFC, which also able to increase the structural strength	NFC hybrid fiber type	Natural + synthetic fiber	Natural + natural fiber	

created through combination of rectangular-shape cross section, reinforced with V-shape ribs and adding synthetic fibers to form hybridized NFC materials, which is able to achieve similar structural strength for the component as the existing circular shape steel-based ironing board legs. Just by combining two design features which are the cross-section shape and ribbing pattern, a total of nine (9) possible solution ideas for the new ironing board leg design were able to be created. Moreover, the potential solution ideas for similar application can be expanded into 18 new ideas by additional combination with two (2) variation of hybrid NFC configurations as listed in the Morphological chart. Figure 2.6 shows several examples of the conceptual design ideas generated through the TRIZ-Morphological chart application for the new NFC ironing board leg component.

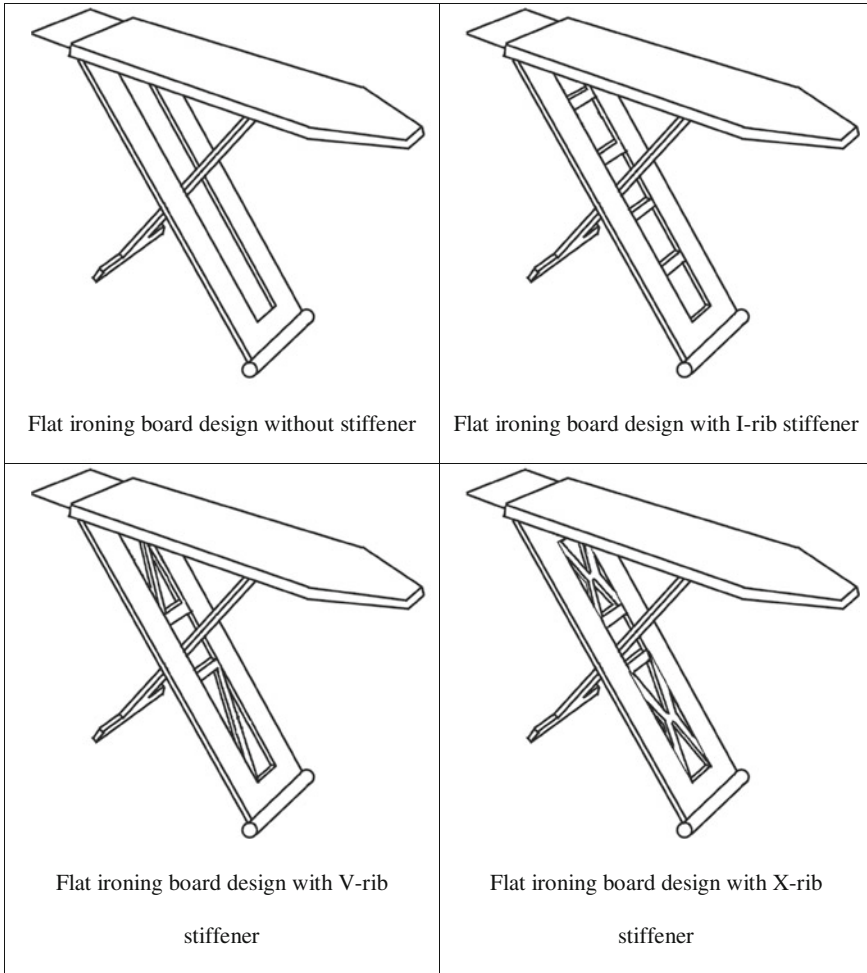


Fig. 2.6 Example of new conceptual designs of eco-friendly ironing board leg component

As shown in Fig. 2.6, by identifying different type of ribs possible to be embedded for the new leg design for improved structural stiffness through the TRIZ-Morphological chart method, four (4) example of new ironing board conceptual design were developed which able to address the engineering contradiction faced in this case study. Alternative leg designs using NFC material were formulated which able to be incorporated with other existing ironing board components in the whole engineering system, without the need to change the principle of operation for the product. The scissors-type folding mechanism is also selected for all the developed conceptual designs similar to the existing design, as the folding mechanism able to provide users with quick and easy adjustment of the ironing board height.

2.4 Summary

In overall, the conceptual design development of NFC products is aimed to create the initial design solution in term of the product shape based on the customer design requirements. The conceptual design process can be conducted using concurrent engineering methods such as brainstorming, TRIZ, Morphological chart, BOS and biomimetics method. Through the case study on ironing board product development, it is shown that the use of concurrent engineering method, particularly the integrated TRIZ-Morphological chart method was able to generate innovative design solutions despite the existing limitation on the structural properties of the NFC material, while still able to achieve the intended structural performance. Such example also showcased the potential of more NFC products to be produced for higher load bearing applications, breaking the current limitation through the aid of innovative conceptual design process.

References

- Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. New York: HarperCollins Publisher Inc.
- Boothroyd, G. (1994). Product design for manufacture and assembly. *Computer-Aided Design*, 26 (7), 505–520.
- Burns, L. A., Mouritz, A. P., Pook, D., & Feih, S. (2012). Strength improvement to composite T-joints under bending through bio-inspired design. *Composites Part A Applied Science and Manufacturing*, 43, 1971–1980.
- Cascini, G., Rissone, P., Rotini, F., & Russo, D. (2011). Systematic design through the integration of TRIZ and optimization tools. *Procedia Engineering*, 9, 674–679. <http://doi.org/10.1016/j.proeng.2011.03.154>.
- Easterling, K. E. (1990). *Tomorrow's materials* (2nd ed.). London: The Institute of Materials.
- Helms, M., Vattam, S. S., & Goel, A. K. (2009). Biologically inspired design: Process and products. *Design Studies*, 30(5), 606–622. <http://dx.doi.org/10.1016/j.destud.2009.04.003>.
- Ilevbare, I. M., Probert, D., & Phaal, R. (2013). A review of TRIZ, and its benefits and challenges in practice. *Technovation*, 33(2–3), 30–37. <http://dx.doi.org/10.1016/j.technovation.2012.11.003>.
- Kim, Y. S., & Cochran, D. S. (2000). Reviewing TRIZ from the perspective of axiomatic design. *Journal of Engineering Design*, 11(1), 79–94. Retrieved from <http://dx.doi.org/10.1080/095448200261199>.
- Kremer, G. O., Chiu, M.-C., Lin, C.-Y., Gupta, S., Claudio, D., & Thevenot, H. (2012). Application of axiomatic design, TRIZ, and mixed integer programming to develop innovative designs: a locomotive ballast arrangement case study. *The International Journal of Advanced Manufacturing Technology*, 61(5–8), 827–842. <http://doi.org/10.1007/s00170-011-3752-1>.
- Li, S. H., Zeng, Q. Y., Xiao, Y. L., Fu, S. Y., & Zhou, B. L. (1995). Biomimicry of bamboo bast fiber with engineering composite materials. *Materials Science and Engineering C*, 3, 125–130.
- Li, T. (2010). Applying TRIZ and AHP to develop innovative design for automated assembly systems. *The International Journal of Advanced Manufacturing Technology*, 46(1–4), 301–313. <http://doi.org/10.1007/s00170-009-2061-4>.
- Luttrupp, C., & Lagerstedt, J. (2006). EcoDesign and The Ten Golden Rules: Generic advice for merging environmental aspects into product development. *Journal of Cleaner Production*, 14 (15–16), 1396–1408. <http://doi.org/10.1016/j.jclepro.2005.11.022>.

- Mahmood, A., Sapuan, S. M., Karmegam, K., & Abu, A. S. (2016). Development of kenaf fibre-reinforced polymer composite Polytechnic chairs. In *Proceedings of the 5th Postgraduate Seminar on Natural Fiber Composites* (pp. 38–42). Serdang, Selangor, Malaysia.
- Mansor, M. R., Sapuan, S. M., Hambali, A., Zainudin, E. S., & Nuraini, A. A. (2015a). Conceptual design of kenaf polymer composites automotive spoiler using TRIZ and Morphology chart methods. *Applied Mechanics and Materials*, 761, 63–67. <http://doi.org/10.4028/www.scientific.net/AMM.761.63>.
- Mansor, M. R., Sapuan, S. M., Salim, M. A., Akop, M. Z., Musthafah, M. M., & Shaharuzaman, M. A. (2016). Concurrent design of green composite products. In D. Verma, S. Jain, X. Zhang, & P. C. Gope (Eds.), *Green approaches to biocomposite materials science and engineering* (pp. 48–75). Hershey, USA: IGI Global.
- Mansor, M. R., Sapuan, S. M., Zainudin, E. S., Nuraini, A. A., & Hambali, A. (2014). Conceptual design of kenaf fiber polymer composite automotive parking brake lever using integrated TRIZ–Morphological Chart–Analytic Hierarchy Process method. *Materials & Design*, 54, 473–482. <http://dx.doi.org/10.1016/j.matdes.2013.08.064>.
- Mansor, M. R., Sapuan, M. S., Zainudin, E. S., Nuraini, A. A., & Hambali, A. (2015b). Life cycle assessment of natural fiber polymer composites. In K. R. Hakeem, M. Jawaid, & O. Y. Alothman (Eds.), *Agricultural biomass based potential materials* (pp. 121–141). London: Springer International Publishing. <http://doi.org/10.1007/978-3-319-13847-3>.
- Mastura, M. T. (2017). *Concurrent conceptual design and materials and manufacturing process selection of hybrid natural/glass fiber composite for automotive anti roll bar*. Ph.D. Thesis, Universiti Putra Malaysia.
- Mastura, M. T., Sapuan, S. M., Mansor, M. R., & Nuraini, A. A. (2017a). Environmentally conscious hybrid bio-composite material selection for automotive anti-roll bar. *International Journal of Advanced Manufacturing Technology*, 89, 2203–2219.
- Mastura, M. T., Sapuan, S. M., Mansor, M. R., & Nuraini, A. A. (2017b). Manufacturing process selection for natural fibre composites in a concurrent engineering environment. *Advances in Mechanical Engineering*, (under review).
- Mastura, M. T., Sapuan, S. M., Mansor, M. R., & Nuraini, A. A. (2017c). Conceptual design of a natural fibre-reinforced composite automotive anti-roll bar using a hybrid approach. *The International Journal of Advanced Manufacturing Technology*, 91(5–8), 2031–2048.
- Pugh, S. (1991). *Total design: Integrated methods for successful product engineering*. Wokingham, England: Addison-Wesley Publishing.
- San, Y. T., Jin, Y. T., & Li, S. C. (2009). *TRIZ: Systematic innovation in manufacturing*. Selangor: Firstfruits Sdn Bhd.
- Sapuan, S. M. (2017). *Composite materials: Concurrent engineering approach*. Oxford: Butterworth-Heinemann.
- Sapuan, S. M., & Mansor, M. R. (2014). Concurrent engineering approach in the development of composite products: A review. *Materials & Design*, 58, 161–167. <http://doi.org/10.1016/j.matdes.2014.01.059>.
- Sapuan, S. M., & Mansor, M. R. (2016). Design of natural fiber-reinforced composite structures. In R. D. S. G. Campilho (Ed.), *Natural fibre composites: Overview and recent developments* (pp. 255–278). Boca Raton: CRC Press.
- Shaharuzaman, M. A., Sapuan, S. M., & Mansor, M. R. (2016). Composite side door impact beam: A review. In *Proceedings of the 5th Postgraduate Seminar on Natural Fiber Composites* (pp. 70–73). Serdang, Selangor, Malaysia.
- Sheu, D. D., & Lee, H.-K. (2011). A proposed process for systematic innovation. *International Journal of Production Research*, 49(3), 847–868. <http://doi.org/10.1080/00207540903280549>.
- Silvester, S., Beella, S. K., Van Timmeren, A., Bauer, P., Quist, J., & Van Dijk, S. (2013). Exploring design scenarios for large-scale implementation of electric vehicles: The Amsterdam

- Airport Schiphol case. *Journal of Cleaner Production*, 48, 211–219. <http://doi.org/10.1016/j.jclepro.2012.07.053>.
- Sutton, R. I., & Hargadon, A. (1996). Brainstorming groups in context: Effectiveness in a product design firm. *Administrative Science Quarterly*, 41(4), 685–718.
- Yu, H., & Fan, D. (2012). Man-made boards technology trends based on TRIZ evolution theory. *Physics Procedia*, 33, 221–227. <http://dx.doi.org/10.1016/j.phpro.2012.05.055>.
- Yusof, N. S. B., Sapuan, S. M., Sultan, M. T. H., Jawaid, M., & Maleque, M. A. (2016). Development of automotive crash box : A review. In *Proceedings of the 5th Postgraduate Seminar on Natural Fiber Composites* (pp. 27–29). Serdang, Selangor, Malaysia.

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