Optimisation of Product Design through QFD, AHP, Entropy and TOPSIS Method: A Case Study of a Bathtub

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Abstract

This paper proposes a hybrid framework combining AHP (Analytical Hierarchy Process), QFD (Quality Function Deployment), Entropy and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to incorporate customer preference and perception into the process of product development. QFD is a useful analysing tool in product design and development to identify these latent customer requirements. In this paper, first by using AHP several customer requirements are identified and prioritised. Secondly, by using fishbone diagram the relationship between technical attributes and customer requirements are listed and these relationships are put in a house of quality. Entropy method is used to calculate sales point. Afterward, TOPSIS method is used to find the best and worst alternative solution. The proposed method is used for evaluating the performance of the bathtub. Then the rankings of the four renowned bathtub companies are determined according to their results.

Keywords — *QFD, Customer Requirements, AHP, Entropy Method, TOPSIS*

I. INTRODUCTION

As long as the demand of bathtub is concerned its popularity is found spreading over high paid income groups and fat salary earners aside from businessmen in urban areas in Bangladesh and looks incredibly and continued promising in its demand. Then only source of the supply side of bathtub is importing that is unlikely worth both in the sense of financial gauge in the form of inherent taxation as well as miss-matched anthropometric characteristics. Hence, two points are set in the same table are brought as the cause of study, therefore the objectives of this study are to optimise cost through redesigning a bathtub in such a way (by using QFD, AHP and TOPSIS) that it can be produced with cost effectively vis-a-vis appropriate anthropometric characteristics.

The appearance of the QFD practice performs accomplishing implications in the meaning of streamlining the manufacturing procedure and expanding the revenue benefits while escalation applied on the products are gratifying the consumer demands. So, it is an important and so far unique, tool for new product's successful development. Usually it is used in the early phase of new or improved products design process and could support the process from problem identification to design specifications. The AHP is a decision support tool which is used to solve complex decision problems, a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. It has been widely-used multi-criteria decision-making technique for prioritising decision alternatives of interest in the last 2 decades. The other one is a fishbone diagram, also called a "cause and effect" diagram or Ishikawa diagram, is a visualisation tool for levelling the conceivable causes of an issue in order to identify its source originator. It is helpful for brainstorming conference to spot consultation. Subject to successful group has brainstorming all the available issues for a problem, the facilitator helps the group to rank the potential causes according to their level of significance and blueprint a hierarchy. The blueprint of the diagram as considered and compared with a skeleton of a fish. Fishbone diagrams are commonly created right to left, with individual enormous "bone" of the fish branching out to include minor bones with much elements as extrude. Fishbone diagrams are used in the "analyse" stage of Six Sigma's DMAIC (define, measure, analyse, improve, control) path for problem settling. Thereafter, the Entropy method is used for analysing sales point by which absolute weight can be gained. Different weighting methods can be used to obtain the weights in TOPSIS model. These weighting methods can be summarised into three kinds, objective weighting method [1-3], subjective weighting method [4] and combination weighting method [3, 5].

This study aims at examining the applicability of QFD, AHP and TOPSIS to shift customer expectations and design quality into the product through a case study on the cast iron bath tub. For this purpose, customer needs and product requirements are determined through direct interviews, observation and data analyses. Customer needs are quantified and prioritised on the hierarchy diagram providing accurate ratio-scale priorities. Following the categorisation and prioritisation of customer needs, the requirements were then converted into quality characteristics. Consequently in this case-study, QFD and augmented it with the AHP can be successfully applied in the case and findings demonstrate that some solutions can be suggested for optimisation of the product reasonably.

II. METHODOLOGY

The cast iron products have been selected for this research, based on not paying attention to achieved significance by its aesthetical assets like outline, pattern, colour and material due to the expanding rivalry status of the market solely, but also emphasised on underlying anthropometric and hygienic properties along with ergonomics as fathomed with the QFD function. In this research, most convenient and fundamental structure of a bathtub is searched with the help of other method naming AHP. The selection process is based on the calculation of scores for alternatives. The Focal point in the AHP method is the pair-wise comparison used to calculate the relative weights of criteria, and consequently to develop an overall ranking of alternatives. Saaty [6] divided an Importance on scale between two elements.

The AHP procedure involves six essential steps [7]

(1) Defining the unstructured problem (2) Developing the AHP hierarchy (3) Doing Pair- wise comparison (4) Estimating the relative weights (5) Checking the consistency (6) Obtain the overall rating

The next step is to construct a house of quality matrix. At first, data should be collected from gembas (the place where customers and consumers meet up). After collecting data the customer requirements will be identified. In product planning stage the customer requirements are set up on the left side of the matrix. Therefore, in next step it is to evaluate prior generation products against competitive products from the AHP and hence product specifications are established as per customer requirements. The relationship between product specification and customer requirements are established using the fishbone diagram. Ranking the present customer requirements and necessity of target the future plan, the improvement ratio is to be produced. Between product specifications the relational attributes like strong, medium or weak are identified. Developing a difficulty rating and analysing the matrix and finalising thereafter the product development strategy will be finished the product planning stage. In concept selection and product designing stage critical concepts are identified and design stage manufacturing processes are evaluated in the process flow. Process quality control eases the way of designing by identifying critical processes, dimensions and characteristics.

For each element of the hierarchy structures all the associated elements are belong to low hierarchy class.

$$A = \begin{vmatrix} 1 & \frac{w_1}{w_2} & \cdots & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_q} & \frac{w_n}{w_2} & \cdots & \cdots & 1 \end{vmatrix} \text{........(1)}$$

Where A= comparison pair wise matrix,
W_1= weight of element 1,
W_2= weight of element 2,
W_n= weight of element n.
The matrix is a square matrix of nxn dimension.
Some methods like Eigen value method is used to calculate the relative weights of elements in pair-wise comparison matrix. The relative weights (W) of matrix A is obtained from following equation: $(A - \lambda_{max} I) * W = 0$.............(1)
Where λ(max) = the biggest Eigen value of matrix A, I= unit matrix. In this step the consistency property of matrices is checked to ensure that the judgments of decision makers are consistent. For this calculation some pre-parameters are needed. Consistency Index (CI) is calculated as: CI=λ(max)/(n-1)................(2)
The formulation of CR is $CR = \frac{CI}{RI}$ ....(3)
Where CI= Consistency index, RI= Random index.
Steps of TOPSIS method are:
(1) Development of the matrix, (2) Construct normalized decision matrix, (3) Construct normalized weighted decision matrix, (4) Determine ideal and negative ideal solution, (5) Determine positive and negative ideal separation measure (6) Find the closeness rating and Find the best solution
Entropy method is used with respect to calculating sales point.

Entropy is a measure for the amount of information (or uncertainty, variations) represented by a discrete probability distribution,p_1;p_2;:::;pL

$$E(W_1) = -\Phi_L \sum_{l=1}^{L} p1i \ln(p1i) \text{ ......(4)}$$

$$E(W_m) = -\phi_L \sum_{l=1}^{L} p_{ml} \ln(p_{ml}) = -\phi_L \sum_{l=1}^{L} (X_{ml}/X_m) \ln(\frac{X_{ml}}{X_m}) \text{...(5)}$$

All these E,(W_m) values, after normalisation:

$$e_1 = \frac{E(W)_1}{\sum_{m=1}^{15} E(Wm)}$$

Where, M=1,2,3…m ....(6)

At first, it is required to identify decision problems and then needed to identify how criteria affect the problem. Then a comparison matrix is constructed which is a square matrix of nxn dimension. When two criteria of the same type are compared then it is numbered as “1”. Every number in diagonal position will be numbered as “1” because it indicates comparisons same requirement with each other. The AHP plan matrix is shown in table 1. In this table an integer means the row entry which is more important than column entry. When the column is more important, and then is inversely considered. For instance, if it is compared that the first customer need with third requirement slip resistance floor first need has very strong importance than third one. For displaying this comparison, use 7 for second component in horizontal and 1/7 for second one in vertical . After forming the AHP hierarchy, percentage is calculated using the formulae of

$$B = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

Table 1: AHP Plan Matrix

	Good appearance	**easily hand reach switch**	**Slip resistance floor**	**Auto pouring of water**	**Fit in size**	**Comfortable**	**Turbo cleaning**	**Water drainage system must be good**	**bacteria and stain free**	**Long term using**	**Anti-aging detox balance**	**colour**	**Splash guard**	**Water bubble**	**Portable faucet**
good appearance	1	1	7	9	1/5	1/3	1/5	3	1	1/3	3	1/5	3	9	3
easily hand reach switch	1	1	3	7	3	1/5	1/3	5	3	1/3	3	1/3	1	3	3
Slip resistance floor	1/7	1/3	1	3	1/5	1/7	1/7	1/3	1/3	1/7	1/3	1/3	1/5	1/3	1/3
Auto pouring of water	1/9	1/7	1/3	1	1/7	1/7	1/7	1/3	1/3	1/7	1/5	1/9	1/9	1/3	1/5
Fit in size	1	1/3	5	7	1	1/3	1/3	3	1	1/3	3	1	1	3	3
Comfortable	3	5	7	7	3	1	1	5	3	1	3	3	3	5	5
Turbo cleaning	5	3	7	7	3	1	1	5	3	1/3	3	3	3	5	3
Water drainage system must be good	1/3	1/5	3	3	1/3	1/5	1/5	1	1/7	1/5	1/3	1/3	1/5	1/3	1/3
bacteria and stain free	1	1/3	3	3	1	1/3	1/3	7	1	1/7	3	1/3	3	3	3
Long term using	3	3	7	7	3	1	3	5	7	1	5	5	3	5	5
Anti-aging detox balance	1/3	1/3	3	5	1/3	1/3	1/3	3	1/3	1/5	1	1/5	3	3	1
colour	5	3	7	9	1	1/3	1/3	3	3	1/5	5	1	3	3	9
Splash guard	1/3	1	5	9	1	1/3	1/3	5	1/3	1/3	1/3	1/3	1	5	1
water bubble	1/9	1/3	3	3	1/3	1/5	1/5	3	1/3	1/5	1/3	1/3	1/5	1	1/3
portable faucet	1/3	1/3	3	5	1/3	1/5	1/3	3	1/3	1/5	1	1/9	1	3	1

To calculate B1 .vector
B11=1/1+1+0.1+0.1+1+3+5+0.3+1+3+0.3+5+0.3+0.1 +0.3=0.005. Thus, every element of B is Calculated, which will give us C vector and by dividing the row summation to the number of elements will give us weight of customer requirements. The next step is determining the D matrix which will be denoted as a multiplication of AHP plan matrix and weighted matrix (AxW). The later step is to calculate the Eigen value by dividing each D and W values to each other. Here the Consistency index (CI) becomes
CI=(λ_max-n)/(n-1) = (17.9542-15)/(15-1) =0.1568
Where λ_max= Eigen value If CR value is less than 0.10 then the result becomes consistent.
CR=CI/RI=0.1568/1.59=0.099
As the CR value is less than 0.1 it can be said that AHP analysis is consistent. With the range of 0.04 importance’s of weights are then prioritized from W vector. Then the ranks are given to the customer requirements (table 2)

Table2 : Importance Weights of Customer Requirements

Customer Requirements	**ranks**
Good appearance	2
Easily hand reach switch	2
Slip resistance floor	1
Auto pouring of water	1
Fit in size	2
Comfortable	4
Turbo cleaning	4
Water drainage system must be	1
Bacteria and stain free	2
Long term using	5
Anti-aging detox balance	2
Color	3

Splash guard	2
water bubble	1
portable faucet	1

The following stage demonstrates us that top critical expectations of the customers may demand major changes in the design which would also cause a chain reaction between other technical aspects of the product or in the different phases of manufacturing process. As it can be understood easily, looking at these details and relating them to each other will enable us to correspond to the other customer needs as well. So, next step is to create the fishbone diagram (figure 1).

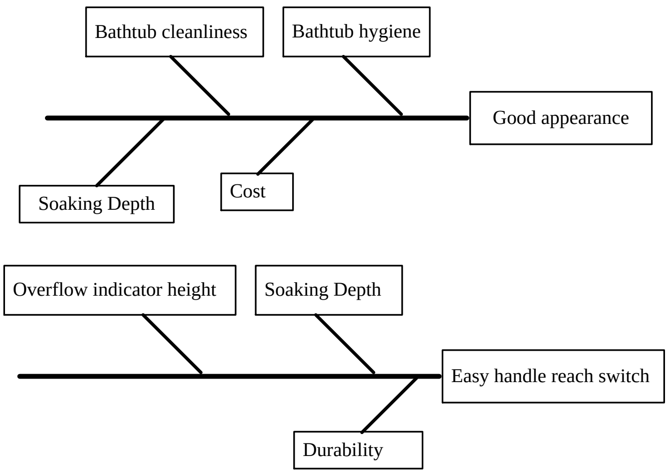

Fig. 1 Fishbone Diagram for Identifying the Relationship Between Customer Requirements and Technical Attributes

For calculating entropy two famous bathtub company and three customers is chosen who are using bathtub. Then, ask them to scale the identified customer requirements and average this value. For good appearance three customers gives Apollo company 3,3,7 respectively and the same three customers give Duravit company 5,3,5 respectively. After averaging the value is 4.3 and 4.3 respectively. Then, it can compote the total score of W1::X1=x11+x12=4.3+4.3=8.6and obtain the probability
Distribution of W1:

P11=x11/x1=4.3/8.6=0.5P12=x12/x1=4.3/8.6=0.5

The entropy of W_1 is then computed using as

$$E(W_1) = -\Phi_L \sum_{I=1}^{L} \text{p1i} \ln(\text{p1i})$$
=-[0.50ln(0.50)+ 0.50ln(0.50)]=1

Ii can obtain the same way the entropy for each of the 15 customer needs.

(1,0.996855,0.996855,0.992774,0.998985,0.9798687, 0.9838712,0.998196,0.995939,0.99691,0.998196,1,1, 1,0.996855) The last step is to find the bath tub C1 ‘s competitive priority ratings on the W1 ::e=e1,e2,e3……………e15 =(0.067,0.067,0.067,0.066,0.068,0.066,0.066,0.067,0.067,0.067, 0.067, 0.067, 0.067, 0.067, 0.067)

Thus, the relation between all customer requirements and technical attributes are established. The next step is to start the drawing of “House of quality” matrix (table 3). For this purpose, customer requirements have been determined and their importance weights and technical attributes. And this is the turn of fixing them: customer requirements take place in the left side of the house and next to them their importance weights take place. Technical attributes’ place is top and the middle of the house in table 3. For constructing house of quality the relation between the customer requirements and technical attributes are divided in a 1-3-9 scale. For example, slip resistance floor and water discharging floor has a strong importance. Hence, in house of quality CNW must be multiplied with 9. Next target is to scale the customer requirements in 1-5 scale. The plan product will also be customised in a 1-5 scale. Improvement ratio is the ratio of plan product to the current product. As in the table for good appearance current product (CP) is 2 and future plan (P) is 3. Therefore, the improvement ratio becomes 3/2=1.5. From AHP, the importance of weight for good appearance is 2 and from entropy method, the sales point is 0.067. Then, next step is to find the absolute weight which is the multiplication of importance of weight (IW), improvement ratio (IR) and sales point (SP). For good appearance, the value of absolute weight is 0.201 and in the similar way all requirements absolute weights can be possessed and in the following step each customer requirements are shown in a percentage. As, for good appearance CNW is 4.654 percent. Now customer need weight is multiplied by the symbol number (1,3 or 9). The next step is to find the absolute weight by adding each column and after calculating the absolute weight each weight is shown in percentage. From table 3 for soaking depth the absolute weight is 140.8 and technical characteristic weight is 11.51 percent. In the table, at the top of house there exists a correlation ship matrix. It shows that there is a strong relationship between bathtub hygiene and bathtub cleanliness, and there exists a weak relationship between durability and cost.

The first step involves the development of the matrix and the last step is to find the best alternative solution. Here, four renowned bathtub companies are selected and compare the rank between them by using TOPSIS method and this gives the result (table 4).

III.RESULT AND DISCUSSION

The objective of the study was to optimise the use of the bathtub design. Bathtub design was optimized by using four analytical tools: QFD, AHP, TOPSIS and entropy method. QFD, as a management tool, assists project managers to clearly identify customer requirements and emphasise those requirements throughout the project delivery process. In both the conceptual and final design, QFD was able to provide useful information to the project design team by emphasising fulfilment of customer requirements during the design process. The first step was determining the customer requirements. In this step, determined the actual customers and questioned them.

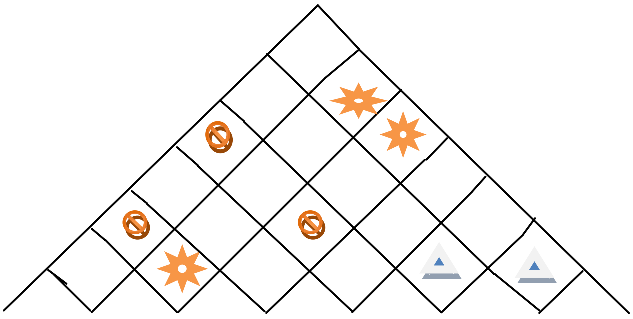

Table 3: House Of Quality Matrix for Bathtub

	Importance weight	Soaking depth	Bathtub hygiene	Bathtub cleanliness	Water discharging holes	Overflow indicator height	Durability	Cost	Current product (CP)	Plan (p)	Improvement ratio IR=P/CP	Sales Point (SP)	Absolute weight AW=IWxIRxSP	Customer need weight CNW=AW/∑AWx100
Good appearance	2	4.65	41.89	4.65				13.96	2	3	1.5	0.067	0.201	4.654
Easy handle reach switch	2	4.13				4.13	12.38		3	4	1.33	0.067	0.17822	4.1266
Slip resistance floor	1	4.65		13.96	13.96	1.55			3	3	1	0.067	0.067	1.5513
Auto pouring of water	1	2.33		2.33	4.65	4.65			2	3	1.5	0.067	0.1005	2.327
Fit in size	2	5.26	5.26			15.78	5.26	5.26	3	5	1.67	0.068	0.22712	5.2588
Comfortable	4		18.34	18.34		18.34			4	4	1	0.066	0.264	6.1127
Turbo cleaning	4	91.87	91.87	91.87					3	5	1.67	0.066	0.44088	10.208
Water drainage good	1			5.58			5,58	1.86	4	5	1.2	0,067	0.0804	1.8616
Bacteria and stain free	2		23.27	69.81				7.76	2	5	2.5	0.067	0.335	7.7567
Long term using	5		93.08		93.08		279.24	31.03	1	4	4	0.067	1.34	31.027
Anti-aging detox balance	2		13.96					41.89	2	3	1.5	0.067	0.201	4.654
Colour	3					6.19		6.19	3	4	1.33	0.067	0.26733	6.1898
Splash guard	2	23.27				7.76			2	5	2.5	0.067	0.335	7.7567
Water bubble	1	4.65				13.96			1	3	3	0.067	0.201	4.654
Portable faucet	1			1.86				5.58	4	5	1.2	0.067	0.0804	1.8616
Absolute weight		140.8	287.7	206.5	111.7	72.4	296.9	107.9	1224					
Technical characteristics weight		11.51	23.5	16.88	9.13	5.91	24.26	8.82	100					

Table 4 : Determine Best and Worst Solution

Alternatives	c_i	
Apollo	0.498	
Barclays	0.43356	
Whirlpool	0.50257	BEST
Duravit	0.33241	WORST

The next step was prioritising analytical hierarchical process. In this step, prioritised the customer requirements are identified in a scale of 1-5. Priority 1 was for five requirements, priority 2 was for six requirements, priority 3 was for 1 requirement, priority 4 was for two requirements and priority 5 was for one requirements. The most priority was for long term using. Customer wants this requirement as a must. The next most priority was for comfortable and turbo cleaning. In the next step with the comparison of the customer requirements some technical attributes were selected which are depended and construct a house of quality matrix. In the next step, the sales points are determined using the entropy method. In the last step, some of the specification and customer requirements are analysed which can be optimised. The biggest benefit of QFD analysis occurs when integrating it into the final design. During the QFD analysis, the most critical failure modes or failures to fulfil customer requirements are identified (table 5). As the final design is completed, critical bathtub specifications can be made more stringent to reduce or eliminate the failure modes. The analysis also allows the quality control and assurance plans to focus on eliminating failure modes during the production process.

Table 5 : Percentages of Customer Requirements

Good appearance	4.654
Easy handle reach switch	4.1266
Slip resistance floor	1.5513
Auto pouring of water	2.327
Fit in size	5.2588
Comfortable	6.1127
Turbo cleaning	10.208
Water drainage good	1.8616
Bacteria and stain free	7.7567
Long term using	31.027
Anti-aging detox balance	4.654
Color	6.1898
Splash guard	7.7567
Water bubble	4.654
Portable faucet	1.8616

Many requirements are collected and after that top priority requirements were selected only for the next step. Also, questioned them about different company's product specifications.

These percentages are shown figure 2. In the figure it is shown that long term using is the most priority full customer requirements and need to identify which factors will mostly determine how long the product will sustain. The second top most priority is for turbo cleaning and as a factor of the priority basis this subjecting factor also needs to be identified.

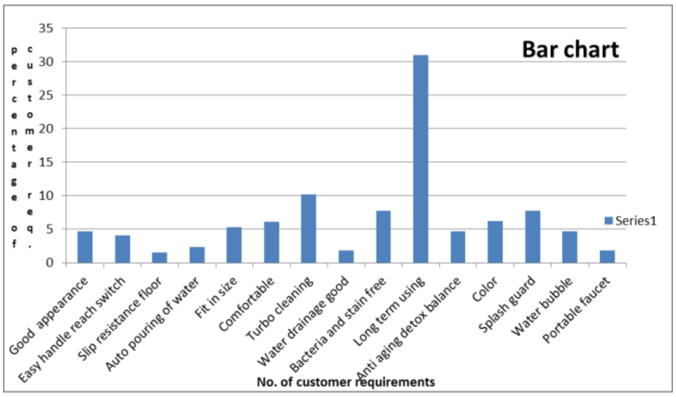

Fig. 2 Percentages of Customer Requirements

Percentages of Combination of technical attributes and customer requirements are shown in table 6 and graphically in fig. 3.

Table 6 : Percentages of Combination of Technical Attributes and Customer Requirements

soaking depth	11.51
Bathtub hygiene	23.5
Bathtub cleanliness	16.88
Water discharging holes	9.13
Overflow indicator height	5.91
Durability	24.26
Cost	8.82

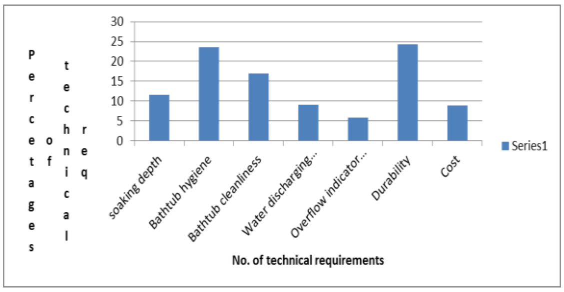

Fig. 3 Percentages of Combination of Technical Attributes and Customer Requirements

In table 6 it is seen that top priority is for durability and bathtub hygiene. Accordingly, there can be a concern for increasing the durability and increasing the bathtub hygiene for the current product. From TOPSIS it is seen that Whirlpool is the best alternative solution and Duravit is the negative best solution. For increasing the bathtub hygiene propose to increase the water absorption capability and for durability propose cast iron materials with minimum possible cost. For safety, also propose a grab bar so that the user can reach his/her feet to the bottom of the bathtub.

IV. CONCLUTIONS & RECOMMANDATION

The objective of the study is to optimise the use of the bathtub design by using four analytical tools: QFD, AHP, TOPSIS and entropy method. As the final design is completed, critical bathtub specifications can be made more stringent to reduce or eliminate the failure modes. The attention is paid also in analysis in relation to the quality control and assurance plans focusing on eliminating failure modes during the production process. Besides, as long as the bathtub hygiene increment water absorption capability improvement and durability are concern cast iron materials are proposed. It is also found that stone and wood bathtubs are likely more worthy than cast iron bathtubs in the sense of durability point of view but idiosyncratically not the same as long as cost efficacy is concerned, so does the cast iron metals bathtub is suggested consequently. In safety perspective, a grab bar is recommend so that the user can reach his/her feet to the bottom QFD provides the project manager with a systematic method of compiling and analysing customer requirements. Subject to further streamlining and optimising it as possible to improve the bathtub design. In the nut-shell, from pragmatic and practicality perspective, this paper has an essential indicative role over specific territory (Bangladesh) and that is the proportional and consistent bathtub manufacturing is underscored.

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