The dynamic changes of customer requirements for sustainable design over time in quality function deployment

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ABSTRACT
The increased awareness and concern over sustainable issues made it important for designers to adopt changes that occur over time to fulfill future customer requirements. Current works in this field do not deal with changes in customer requirements over time towards sustainable design. There is, however, a need to develop a new more flexible method that could integrate sustainable requirements into the sustainable design as well as forecast changes in customer requirements for sustainable design. The main contribution of this research is developing a new method. This method used dynamic quality function deployment for sustainability (dynamic QFDS) to model changes in customer requirements for sustainable design over time. The future forecasting shows how customers are becoming much more aware of sustainable requirements and it also proves that on a yearly basis, customer requirements are increasingly shifting towards sustainable design.

1. Introduction
With the passage of technological innovation, economic competition, and the increasing environmental consciousness over the past years, designers started changing and adopting sustainable designs. The shift towards sustainable design occurred rapidly due to an increase in environmental concerns. With these new developments, many companies started changing their product and service designs, reducing waste disposal problems and became more concerned with the effectiveness of following eco-friendly marketing strategies (Chen & Chai, 2010; Lee, 2009).

In order to obtain sustainability, requirements should change on par with societal, economic, and environmental changes, and adopt these changes while developing new technology (Loorbach, 2010). The dynamics of the market and customer requirements keep changing over time and companies facing this problem need to expect changes in future customer requirements, integrate those changes earlier into the product design process, and also consider changes in sustainable requirements (Schuh et al., 2012). The product designers usually focus on the traditional customer requirements to maximize the profitability of their company. They try to understand the customers and their requirements for the products or service design before or during the life cycle of the
product and mainly observe the issue that is important for a new product and service design. But, according to the emerging trend, it has become more important to consider a sustainable design, to focus on both sustainable and traditional requirements as well as checking out the changes in customer requirements in the future. In order to solve this issue, the designer should predict all the possible changes in customer requirements in the future and integrate these changes into the product or service design.

There are no methods being designed so far that have been implemented to model the changes in customer requirements towards sustainable design. Due to the rapid changes in the economy, environment, global climate, society needs, and the development of new technology, there is a need for a more active approach in dealing with these changes and avoiding the design of unwanted products and services, which might cause a massive loss in case of profit for the company. Thus, there is a need to develop a flexible method that can integrate sustainable requirements as well as traditional requirements to sustainable design and forecast changes in customer requirements for sustainable design over time.

Expected sustainable design elements should be identified from the first step in the product design process. A developed Quality function deployment for sustainability (QFDS) will be used by modifying the house of quality from the QFD methodology, which deploys sustainable requirements and incorporating sustainability aspects into QFD. It will be handling the sustainable design requirements by using the house of quality for sustainability (HQOS) which include the sustainability index, environmental, economic, social requirements (not just the environmental requirements like in the green house of quality) and at the same time the traditional requirements together to support the sustainable design in early stages of the design process and to improve the sustainable design specifications. The usefulness of this methodology lies in the fact that the sustainable requirements are completely integrated into the new product or service design development process by using House of quality for sustainability, and at the same time, when we find the importance ratings of those requirements, this method considers the traditional and sustainable requirements simultaneously. After this process, the evaluation and ranking of all design requirements will be taken into consideration (Kaebernick et al., 2003).

This research presents the new approach to the dynamic quality function deployment for sustainability (Dynamic QFDS), the quality function deployment for sustainability (QFDS) and the dynamic quality function deployment (Dynamic QFD) will be integrated to model the changes in customer requirements for sustainable design over time. And present a case study based on Chinese tablet computers, which has been chosen as the case study in this research. The proposed methodology in this research lead to future spoken and unspoken ecofriendly customer needs, and it can be used by students in the future, in any case, a study that aims to measure the changes in customer requirements from the viewpoint of sustainable design over time.

2. Literature review

During the past few years, numerous methods addressed identifying and integrating environmental requirements into the product and service design. QFD is one of the most used methods, by which designers capture customer requirements, consider each of them, and incorporate them to the product at the design stage.
For more than a decade, the development of new products and the need for introducing sustainable requirements into the design have been discussed in depth (Pezzoli, 1997). However, after identifying the eco-friendly customers and identifying their needs, the question that remains unanswered is how important it is to integrate sustainable requirements into the product and service design, and how can they be compared with the traditional design requirements such as cost, function, and quality (Bhamra et al., 1999). Manufacturing companies still render their production on traditional requirements, and they are looking to produce a high-quality product with low cost and high profit. The sustainable requirements are slowly becoming unavoidable, but at the same time, those requirements increase the cost of its production (Bhamra et al., 1999).

Previous studies used different methods to evaluate and weigh the customer requirements like the Kano method, the Multi-Attribute Utility function (MAUT), and the Analytic Hierarchy Process (AHP). The Kano method evaluates and weighs customer priorities according to customer satisfaction or dissatisfaction. It then classifies customer requirements, puts them in groups, and categorizes them. This method cannot evaluate or rank every and each requirement, or the priority for customers. In the market, customers have various choices, and many options they take into consideration before deciding what they prefer. Considering this, researchers need a method that will enable them to rank all requirements and find the customer priorities. That is why some researchers use the MAUT method. Researchers have used the MAUT method in many fields (Chang & Yeh, 2001) used it in the airline industry, and (Van Calker et al., 2006) applied it in the farming field. The analytic hierarchy process (AHP) has been used by many researchers to express and model the importance ratings of customer requirements (Kwong & Bai, 2003; Li et al., 2009; Raharjo et al., 2009). Some researchers prefer to use the fuzzy AHP method (Kwong & Bai, 2003; Wang, 1999), and many proposed an integration method, which uses AHP and QFD, and has recently been considered as the most popular method to weight the importance ratings of customer requirements. This is because the AHP method uses a scale of 1–9 or 1–5, which makes it more useful than traditional methods, and this scale makes the QCs priorities more significant (Burke et al., 2002). However, the tools that are used to determine the changes in importance rate of customer requirements over time in QFD still need more consideration from researchers.

Many studies have been conducted on QFD for environment (QFDE) and including environmental features within the QFD. (Cristofari et al., 1996) introduced the Green QFD (GQFD) methodology to consider the environmental requirements in the product design process. (Zhang et al., 1999) developed the GQFD-II method that combines ‘Life Cycle Assessment’ (LCA) and ‘Life Cycle Costing’ (LCC) to QFD. (Masui et al., 2003) concentrated on highlighting the ‘environmental voice of customers’ (VOC) and ‘environmental engineering metric’ (EM) for QFD to promote ‘Quality Function Deployment for environment’ (QFDE). (Sakao, 2007) introduced a methodology called ‘QFD-centered design’ which includes three tools: ‘life cycle assessment’ (LCA), ‘quality function deployment for environment’ (QFDE), and ‘theory of inventive problem solving’ (TRIZ), in order to develop environmental design. (Kuo et al., 2009) proposed ‘Eco-quality function deployment’ (Eco-QFD) that includes environmental consideration into QFD to achieve customer satisfaction. Lots of tools for sustainable design have been proposed over the last few years. (Bonvoisin et al., 2014) developed an LCA framework
for estimating the environmental effects of eco-design services that focus on the eco-
design of machines and infrastructure. (Romli et al., 2015) developed a method that
integrates eco-design making (IEDM). The authors integrated life cycle elements, eco-
design stages and developed an eco-design quality function deployment. They studied the
environmental impacts related to manufacturing, the use of the product, and its disposal.
(Lin et al., 2013) used fuzzy QFD method to evaluate the protection of the environment
and global warming. (Firman et al., 2012) proposed a method that helps in decision-
making, by enabling designers to select the best index of sustainability linked to economy
and ecology, as well as enable them to analyze the environmental impacts of their designs.

The main subject of this study is modelling changes in customer requirements for
sustainable design over time. Most of the previous research dealt with customer require-
ments for product design in general (Jin et al., 2016). The studies of (Pusporini et al.,
2013) and (Romli et al., 2015) focused on integrating environmental requirements to
product and service design, and some authors like Younesi and Roghanian (2015) focus
on sustainable product design, while a limited number of researchers studied sustainable
product and service design requirements like Griese (Griese et al., 2005). There are many
studies on changing customer requirements during the production process, but not over
time (Janes et al., 2013; Schuh et al., 2012). At this point, very few studies deal with
changes in customer requirements over time (Schuh et al., 2012b; Buckow et al., 2016;
Raharjo et al., 2011), and none of those dealing with changes in customer requirements
for sustainable design over time.

QFD is a flexible method that can provide more effective approaches that create high
customer satisfaction level and fulfill all their needs, currently or in the future. In this
study, QFD will be used to integrate the sustainable design requirements and prioritize
them by using QFD for sustainability. Dynamic QFD will be used to model the changes in
customer requirements over time.

3. The proposed method: the dynamic quality function deployment for sustainability

3.1. The quality function deployment for sustainability

Quality Function Deployment is a well-known design method, developed in late 1960 in
Japan by Professors Shigeru Mizuno and Yoji Akao (Akao, 1972). QFD is a method used
for transforming customer requirements while company considering customer require-
ments in each phase. QFD can be described as the process of capturing the voice of
customers or users of a product, service or systems development. This method connects
customer requirements with the product’s engineering characteristics. QFD works on
discovering customer requirements, considers each of them and prescribes them to the
product at the design stage. QFD uses matrices called houses of quality (HOQ) to deploy
customer requirements translated to quality characteristics throughout all development
phases (Park et al., 2012).

Most of the studies deal with finding customer requirements for products or services
in general, not for sustainable design. And even when the studies consider sustainable
design, they focused on integrating environmental requirements to the product or service
design by using green house of quality or environmental house of quality, some
researchers used House of Quality for Sustainability and Buildability (HOQSB) in sustainable development studies in which they used the Sustainability and Buildability Index (SBI) (Singhaputtangkul et al., 2013) and rarely addressing product and service designs and their requirements (environmental, economic, social and traditional requirements) which they are the main three elements of sustainability and sustainable design.

In QFDS, this study used house of quality for sustainability (HOQS) to find the relationships between customer requirements (DQ) (environmental, economic, social and traditional requirements), and technical requirements (QC) are represented in matrix form. Figure 1 shows the basic elements of the house of quality for sustainability which has six parts:

1. Demanded quality (DQm) the Whats. Which include the traditional requirements which reflect the customer traditional needs like (Health, Taste, Reuse, status, convenience, Quality, Value for cost, Easy access, Appearance, freshness and smell). And the sustainable requirements (environmental, economic and social requirements).

2. Quality characteristics (QCn) the Hows.

3. Relationship matrix between demanded quality and quality characteristics (Whats and Hows), in Figure 1 Rij reflect the score of the relationship between the ith DQ and the jth QC. Here Strong = 9, Moderate = 3, Weak = 1.

4. Importance rating of demanded quality (IRs).

5. Prioritizing of quality characteristics.

6. Correlation matrix of quality characteristics (Hows vs. Hows) rjn is the correlation score for the jth and nth QCs.

![Figure 1. House of quality for sustainability.](image-url)
3.2. The dynamic quality function deployment

Dynamic QFD is an expansion of the regular QFD which considers changes in customer requirements over time. The Dynamic QFD considers the changes in relative importance rating first. Then quantitatively transform it in the HOQ and find its future uncertainty. The Demanded Quality (DQ) represents the customer requirements (Whats), and Quality Characteristics (QC) represent the technical requirements (Hows). The forecasting results of the voice of eco-friendly customers will be estimated in dynamic QFD, and then used in the HOQ. Figure 2 shows the dynamic QFD model of mDQs and nQCs. DQs here include the traditional requirements. The first step is to normalize the correlation matrix (Rij), and taking into account the relationship between the QCs, by using the Wasserman method proposed by Wasserman (1993).

Most of the previous research dealt with customer requirements for product design in general, and some authors focused on integrating environmental requirements to product and service design, and on sustainable product design, while a limited number of researchers studied changing customer requirements during the production process, but not over time, and very few studies deal with changes in customer requirements over time, and none of those dealing with changes in customer requirements for sustainable design.

3.3. The dynamic quality function deployment for sustainability approach

Dynamic QFDS model expands the inserted customer requirements of the quality function deployment matrix while using the voice of eco-friendly customer’s requirements and their importance rating (IR) values that were collected through a specific period of time. Figure 3 shows the dynamic QFDS model of mDQs and nQCs.

![Figure 2. Dynamic QFD model.](image-url)
The first step is to normalize the correlation matrix \((R_{ij})\), and taking into account the relationship between the QCs, by applying the Wasserman approach (Wasserman, 1993)

\[
R_{ij}^{\text{norm}} = \frac{\sum_{k=1}^{n} R_{ik}y_{kj}}{\sum_{j=1}^{n} \sum_{k=1}^{n} R_{ik}y_{kj}} \quad i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n
\] (1)

The value of \(R_{ij}^{\text{norm}}\) refers to the normalized correlation between \(i\)th DQ and the \(j\)th QC entries, and the correlation value between the two entries \(j\)th QC and the \(k\)th QC refers to \(y_{jk}\). If the relation between the \((y_{jk})\) is supposed to be non-existent, the upper equation can be simplified as follows:

\[
R_{ij}^{\text{norm}} = R_{ij} / \sum_{j=1}^{n} R_{ij}
\] (2)

The QCs priorities in the Dynamic QFDS model calculated by taking the value of \(R_{ij}^{\text{norm}}\) and the predicted IR \((IR_{i,k+1})\), as shown in equation (3):

\[
\hat{\mu}_j = \sum_{i=1}^{m} R_{ij}^{\text{norm}} \cdot IR_{i,k+1}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n
\] (3)

\(\hat{\mu}_j\) = the mean of predicted QC \(j\) priority, \(IR_{i,k+1} = DQ_i\) predicted IR, \(k\) = last period of the variables. In Figure 3, the standard deviation of the predicting residual (Sdi) represents the future uncertainty of the predicted IR. The values of the standard deviation can be converted to the Sd of the QC \(j\) predicted priority by employing the variance shown in the equation below:

\[
\hat{\sigma}_j = \sqrt{\sum_{i=1}^{m} R_{ij}^{\text{norm}} \cdot \hat{\sigma}_i^2} \quad j = 1, 2, \ldots, n
\] (4)

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**Figure 3.** Dynamic QFDS model.
$\hat{\sigma}_j$ is the standard deviation of predicted priority of QCj and $\hat{\sigma}_j^2$ is the variance of the predicting residual of IRi or the squared value of Sdi. Because of the normalization of the (R_ij norm) value, the variance value could be minimized.

3.3.1. The forecasting technique

In the Dynamic QFDS it is used to measure changes in the importance rating values over time. Thus, it reflects the future voice of the eco-friendly customers (FVOC) of the predicted IR. It is suitable to use when the data reflects a short period of time and when we have limited and short time series data.

Compositional double exponential smoothing (CDES). (Brow 1961.n and Meyer, 1961) method is perfect for modelling changes in data. CDES formulas are shown below:

$$S_t = \alpha \ast Y_{t-1} + (1 - \alpha) \ast S_{t-1}$$ (5)

$$S_t = \alpha \ast Y_t + (1 - \alpha) \ast S_{t-1}$$

$$S'_t = \alpha \ast Y_t + (1 - \alpha) \ast S'_{t-1}$$

$$A_t = 2 \ast S_t - S'_t$$

$$B_t = \frac{\alpha}{1 - \alpha} \ast (S_t - S'_t)$$

$$\hat{Y}_t = A_t + B_t \ast P.$$ Where 0 ≤ α ≤ 1 and P ∈ R+ (the real sample space). And St is the forecast value of the importance rating for period t, Y_{t-1} is the actual value of the importance rating for period t-1, and S_{(t-1)} is the forecast value of the importance rating for period t-1.

3.3.2. The future uncertainty

The future uncertainty is calculated by fitting uncertainty of the forecasting model (Raharjo et al., 2009) it is a quantity scalar, developed to estimate the fineness of the model certainty, in a specific period of time t, it estimates the difference between the actual IR values and the fitted IR (IR’) for Demanded Quality (DQi, i = 1 . . . m) as shown in equation (6):

$$Ad_i(IR, IR') = \left( \ln \frac{IR_i}{g(IR)} - \ln \frac{IR'_i}{g(IR')} \right),$$

Where,

$$g(IR) = \sqrt[m]{\prod_{i=1}^{m} IR_i}, \quad g(IR') = \sqrt[m]{\prod_{i=1}^{m} IR'_i}$$ (6)

The summation of m IR values, for a specific period of time t, has to be 1.
4. The proposed methodology

This section will propose the methodology and models of changes in customer requirements for sustainable design. The customer requirements, and the importance rating for requirements were collected through one-on-one interviews and survey questionnaires. The questionnaire for this research contains preferences with respect to each attribute (the technical and sustainable customer requirements) through a specific period of time, and the customers were asked to give relative importance ratings for each attribute in every year. The scale that was used for the design of this questionnaire is a Likert rating scale with a range of 1–9. The data on tablet consumer requirements was compiled based on the literature review (Chen, 2013; Hsu et al., 2012) and interviews. It is separated into five categories (durable, performance, simple to use, structure, and pricing) and comprises 18 items.

To determine the importance ratings values of the customer requirements for sustainable design, quality function deployment for sustainability (QFDS) will be used. Dynamic QFDS will consider the changes in relative importance rating first. It will then quantitatively transform it into the HOQS and find its future uncertainty. The Demanded Quality (DQ) (environmental, economic, social, and traditional requirements) represents the customer requirements (Whats), and Quality Characteristics (QC) represents the technical requirements (Hows). The predicting results of the voice of eco-friendly customers will be estimated in dynamic QFDS, and then used in the HOQS.

The new modelling approach presented in Figure 4 provides the structure of the dynamic quality function deployment for sustainability.

4.1. Methodology procedures

The methodology is based on two essential tools and their merger: the dynamic quality function deployment (dynamic QFD) and the quality function deployment for sustainability (QFDS). QFDS will evaluate the customer requirements from a sustainable viewpoint, the dynamic QFD will be used to model changes in customer requirements over time. After determining the weights of customer sustainable requirements and find the customer importance rating values. Then, we will be determining the ranking of customer requirements for sustainable design. The methodology steps for dynamic QFDS are as follows:

1. Construct the house of quality for sustainability (HOQS) by using QFDS steps, such as determining the customer traditional and sustainable requirements (demanded quality) DQs, and the technical requirements for quality characteristics (QC).
2. Determining the relationship between DQs and QC to determine the weights of customer requirements and obtain the importance rating (IR) values from the customers using Likert rating scale.
3. Finding the actual importance rating values over time of each customer requirement for n periods. These importance rating values over time should be obtained from a specific segment of customers.
(4) Fitting the importance rating data change over time by using a forecasting technique called ‘compositional double exponential smoothing’.
(5) Measuring the forecasted IR (IRi,k + 1) for each customer requirement and for future uncertainty, that is, the standard deviation of forecasting residual.
(6) Computing the mean and standard deviation of forecasted technical requirements for sustainable design priorities and finding their ranking in the QFD.

5. A case study

Chinese tablet computers have been chosen as the case study in this research because it is one of the most notable examples of sustainable design: they keep up with the rapid changes in technology, they change almost every year according to the changes in
customer requirements and new technology, they are familiar to everyone and available everywhere. This study proposes the dynamic QFDS model to answer the questions: what the customers want in the future and what they prefer the most?

5.1. Data collection and the sample

This study used self-administered questionnaire and collected the customer’s detailed information through a questionnaire survey conducted over a sample of people belonging to different ages, education, marital status and income groups. In order to ensure an acceptable number of responses, a group of 10 graduate students were hired to distribute the questionnaires in five universities in China. These universities are: Northwestern Polytechnical University (NWPU) in Xian, North China Electric Power University (NCEPU) in Beijing, Shanghai Jiao Tong University (SJTU) in Shanghai, Northeast Forestry University (NEFU) in Harbin, Chengdu University of Technology (CDUT) in Chengdu. The candidates were students, workers, teachers and the student’s families which respondents a wide sample of candidates which they are different in their Sex, Age, Marital status, Educational levels and Income. The scale of sampling was carried out from February 2017 to July 2017. The primary data was collected through a questionnaire survey conducted over a sample of 900 people belonging to different cities. Out of 900 questionnaires distributed, 350 were capable of getting qualified for the valid data and the people responded with a corresponding (39%) who properly filled out the questionnaires. The number of questionnaire sets received with proper answers from every university in five different cities is shown in the table below.

5.2. Step by step analysis

The methodology for dynamic QFDS, to model changes in customer requirements for sustainable design over time are as following steps:

Step 1: Constructing the house of quality for sustainability (HOQS) by using QFDS steps, such as determining the customer’s traditional and sustainable requirements (demanded quality) DQs, and the technical requirements for quality characteristics (QCs).

Step 2: Determining the relationship between DQs and QCs to find the customer requirement weights and obtain the importance rating (IR) values from the customers using a Likert rating scale.

It can be seen from Figure 5 the sustainable design with Recyclable, Energy Saving, Easily Maintenance, safe, No Toxically Material Released, Durability, information security, and less waste are becoming the most important issue for the customers. They reflect the increase in their awareness of the sustainable consideration and sustainable designs that would meet the sustainable requirements. This shows how the customer requirements are changing towards sustainable requirements and becoming more aware of the importance of reduction of the environmental crises and pollution. Especially saving energy which was the highest weight among all the customer requirements for the Chinese tablets to show us how much it is important for the customer even more than the price which means the customers are ready to pay more for the Chinese tablets if it
saves energy which preferred more by them and satisfied them more when the design fulfill their requirements toward protecting the environment and save the rare natural resources.

Step 3: Finding the actual IR values over time of every customer requirement for a specific period of time. The survey questionnaires give the data about the preferences for the Chinese tablets with respect to each DQ (the technical and sustainable customer requirements) for a certain length of time, here in this research was for five years from 2013 to 2017.

To simplify the HOQS we will summarize the DQs into five DQs. The IR for the five DQs, are, ‘sustainable’ (IR1), ‘easy to use’ (IR2), ‘Structure’ (IR3), ‘Performance’ (IR4) and ‘Cost’ (IR5), they are calculated by finding the summation of all values of every DQ in Figure 5. Here the summation of QDs priorities has to be 1.

Step 4: Modelling changes in customer requirements over time. Use the forecasting technique to estimate the changes in IR data for the 5 years (Raharjo et al., 2009) see formula (5). The optimal parameter is \((\alpha^* = 0.5)\) for the CDES as it is given in (Raharjo et al., 2009). The IR values of the five DQs are shown in the first six columns in Table 2.

Step 5: Obtain the predicted value of the IR values for the DQs. These predicted values represent FVOC the future voice of the customers. Measure the predicted IR \((IR_i, k + 1)\) for the five DQs and future uncertainty. The future predicted IR values for IR1, IR2, IR3,
IR4, and IR5, for the year 2018 are shown in the bold last row in the next five columns after the sixth column in Table 1 and they are (t = 2018), are 0.241, 0.192, 0.216, 0.212, and 0.250. This was obtained by using the compositional double exponential smoothing method, formula (5). As shown in Table 2 relative importance of the price (0.250) became higher over time, then the sustainable requirements (0.241). The last five columns represent the fitting error values by using formula (6). The last row under Table 2 represents the future uncertainty that is measured by calculating the Sd of the predicted residual (‘St. Dev of Adi’).

\[
\alpha = 0.5, \text{ St. dev, of Adi} = 0.0072, 0.0076, 0.0121, 0.0042, 0.0139.
\]

According to Raharjo (Raharjo et al., 2009), the Compositional Double Exponential Smoothing (CDES) method gives far higher adaptability to changing requirements over time and it is better for short-term forecasting. The performance of CDES method is better than other methods such as the principal component analysis (PCA) and the dimension-reduction approach through a hyperspherical transformation (DRHT). Because CDES method implements a lower fitting error mean value and lower fitting error variability value. Besides, the CDES method’s low standard deviation value indicates that the prediction’s accuracy will be high. To put it another way, the future uncertainty determined using this method will be relatively low. The findings, as shown in Table 2, confirm the validity of the proposed method, since the fitting error and standard deviation values were both low.

Figure 6 shows the predicted IR values and the future voice of the customer’s values for the Chinese tablets in 2018, (IR5) which represents the cost took the highest rank, the sustainable requirements (IR1) was in the second place and was very close to the importance value of the cost, then the Structure and performance requirements (IR3, IR4) and the last requirement was easy to use (IR2).

In Figure 7, The Connected lines represent the actual IR values, and dashed lines represent predicted IR values, IR1, IR2, IR3, and IR4 for the 5 years.

Figure 7 shows that the IR of DQ1 (‘sustainable’) increases over time, but the IR of DQ5 (‘cost’) diminished over time. The IR of DQ2 and DQ3 (‘easy to use’) (‘structure’) are steady, and the IR DQ4 (‘performance’) did not change that much. These observations could be very reliable if considered in the planning of sustainable design.

Step 6: Calculate the mean \( \hat{\mu}_j \) of predicted QCs’ priorities then find the standard deviation (\( \hat{\sigma}_j \)) of them by employing the formulas (3) and (4), as shown in Figure 8.

\[
R_{ij} / \sum_{j=1}^{n} R_{ij}
\]
### Table 2. Actual, fitted, predicted, and fitting error values of all IR.

| Time | IR₁ | IR₂ | IR₃ | IR₄ | IR₅ | IR₁’ | IR₂’ | IR₃’ | IR₄’ | IR₅’ | Ad₁  | Ad₂  | Ad₃  | Ad₄  | Ad₅  |
|------|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|
| 2013 | 0.234 | 0.190 | 0.214 | 0.208 | 0.266 | 0.234 | 0.190 | 0.214 | 0.208 | 0.266 | –    | –    | –    | –    | –    |
| 2014 | 0.239 | 0.190 | 0.212 | 0.210 | 0.260 | 0.234 | 0.190 | 0.214 | 0.208 | 0.266 | 0.010 | –0.004 | –0.013 | 0.001 | 0.002 |
| 2015 | 0.238 | 0.193 | 0.217 | 0.212 | 0.251 | 0.237 | 0.190 | 0.213 | 0.209 | 0.263 | –0.007 | 0.011 | 0.015 | 0.006 | –0.022 |
| 2016 | 0.240 | 0.193 | 0.217 | 0.214 | 0.247 | 0.237 | 0.192 | 0.215 | 0.211 | 0.257 | 0.002 | 0.001 | 0.006 | 0.006 | –0.015 |
| 2017 | 0.243 | 0.192 | 0.216 | 0.212 | 0.248 | 0.239 | 0.192 | 0.216 | 0.211 | 0.252 | 0.006 | –0.004 | –0.004 | –0.004 | 0.009 |
| 2018 | 0.241 | 0.192 | 0.216 | 0.212 | 0.240 | 0.239 | 0.192 | 0.216 | 0.211 | 0.252 | 0.006 | –0.004 | –0.004 | –0.004 | 0.009 |

α = 0.5, St. dev. of Ad’ = 0.0072, 0.0076, 0.0121, 0.0042, 0.0139
In Figure 8 it is important to consider the implementation of predicted QCs’ priorities, which are obtained from the customer’s future requirements, as a foundation for optimizing the QCs. Firms may focus on the technical requirements such as usage and disposal in sustainable design by properly predicting the customer future requirements.
Table 3. The statistical tests for DQs.

| N | Minimum | Maximum | Mean | Std. Deviation | Variance | Skewness | Kurtosis |
|---|---------|---------|------|----------------|----------|----------|----------|
| Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Statistic | Std. Error |
| Ad1 | 4 | −.01 | .01 | .0028 | .00364 | .00727 | .00005 | −.887 | 1.014 | .680 | 2.619 |
| Ad2 | 4 | .00 | .01 | .0010 | .00354 | .00707 | .00006 | 1.414 | 1.014 | 1.500 | 2.619 |
| Ad3 | 4 | −.01 | .02 | .0010 | .00607 | .01214 | .00015 | .000 | 1.014 | −1.510 | 2.619 |
| Ad4 | 4 | .00 | .01 | .0023 | .00239 | .00479 | .00002 | −.855 | 1.014 | −1.289 | 2.619 |
| Ad5 | 4 | −.02 | .01 | −.0065 | .00722 | .01443 | .00019 | .000 | 1.014 | −3.832 | 2.619 |

It can be observed from Table 3 of the Anderson–Darling statistic and the normality test of the predicted values for the five customer requirements (DQs). The p-values associated with the statistical tests can take into consideration the value of the predicted priority.

6. Results and discussion

Compared with the studies that deal with changes in customer requirements over time and used dynamic QFD (Schuh et al., 2012b; Buckow et al., 2016; Raharjo et al., 2011) or environmental QFD methods like (Pusporini et al., 2013) and (Romli et al., 2015) that focused on integrating environmental requirements into product and service design, this study not only considers the change in customer’s requirements and integrating environmental requirements. It took a further step based on previous studies by presenting a more extended methodical approach the Dynamic QFDS approach.

This study uses the Dynamic QFDS to identify and evaluate the customer priorities for sustainable design. In addition, priorities’ can be applied to model changes over time. The beneficial use of dynamic QFDS is to predict the future QDs priorities and to enhance the ability of Chinese tablet designers and companies to meet the current and the future customer requirements.

In the final assessment of the results arising from the case study, the users of the Chinese tablets showed increasing preference toward sustainable designs over time and it was in the second place after cost which took the highest rank. Based on previous research cost has a significant role on consumer choice in the purchase decision of the electronic devices (Paulrajan & Rajkumar, 2011). However, other studies show that cost is not the most significant factor that impact the electronic devices purchase decision (Osman et al., 2012). As shown in Figure 6 the sustainable requirements were very close to the cost requirements to reflect changes in customer needs towards the sustainable designs in the future, and reflect the increasing in their concerns of sustainability and preference of the designs that considers the sustainable requirements. Other traditional requirements came after the sustainable requirements like Performance, easy to use and Structure to show how the customer requirements are changing towards the sustainable requirements and become more aware of the importance of sustainability. This result may be because most of the respondents were from university. This result most likely due to the sample distribution. Most of the respondents were teachers or students with a university education level and more concerned over environmental problems.
In Figure 7 the importance rating values marked differences in the QDs for each year. And showed how the customer requirements keep changing over time. Based on the future voice of customers of every QDs, several QDs should get more consideration since its importance keeps growing more and more and may become the most important requirement to meet future customer satisfaction. Like the relative importance weighting of DQ1 (‘sustainable’) which kept increasing over time in increasing way from year 2013 to year 2017 and then the predicted importance rating values for 2018 showed how it will increase too. On the other hand, the importance weighting of DQ5 (‘cost’) it took the highest value but year by year it keeps decreasing which mean it will not be the most important requirement for the customers when they want to buy Chinese tablet like before, so that Chinese tablet designers and companies who use more data analytical should consider different QDs in different ways. They should here give more attention to the sustainable requirements more than the cost because the important weighting for them increases over time then the DQ4 (‘performance’) because the relative importance weighting has a high Possibility to increase in 2018, then DQ2 and DQ3 (‘easy to use’) (‘Structure’) their relative importance has remained constant over time.

7. Conclusions

In order to achieve the research objective, a new approach was developed; that is, dynamic QFDS. This new method integrated dynamic QFD with QFDS, and these two were used combinable as one method. QFDS was used to evaluate the customer requirements from a sustainable viewpoint, the dynamic QFD was used to model the changes in customer requirements over time.

In the final assessment of the case study related to modelling changes in customer requirements for sustainable design over time, the users of Chinese tablets showed increasing preference towards sustainable designs over time. The sustainable requirements were very close to the cost requirements, which reflects the changes in customer needs towards sustainable designs that will appear in the future, and also the increase in their awareness of sustainable designs that would meet sustainable requirements. Traditional requirements like Performance, easy to use and Structure are not preferred over sustainable requirements, it clearly shows how customer requirements are changing towards sustainable requirements, and how customers are becoming more aware of the importance of sustainability.

According to the future voice of customers of each customer requirement (‘sustainable’) which kept increasing over time from year 2013 to year 2017, and the predicted importance rating values showed how it is expected to increase in 2018. Chinese computer designers and manufacturers have to give more attention to sustainable requirements, than to the cost, because their importance weighting is increasing every year.

Dynamic changes in customer needs are one of the biggest difficulties for producers. To face this challenge, they have to be proactive in reacting to future innovations in advance. To obtain this they should also rethink how future changes are being considered. These changes are natural and have to be regarded as routine life where it could represent a great opportunity in the marketplace for these producers. Therefore, considering the proposed approach in this research would keep them up with the future
changes in customer requirements and grant them a distinguished competitive advantage. The main focused point of this approach lies in improving the knowledge of the significant impact of sustainability on the product design.

The approach proposed in this case study focuses particularly on the necessity to observe and track future changes in customer preferences over time. Keeping customers’ needs up-to-date can afford a sustained viable feedback to producers, enabling the company to interact creatively, and giving them the opportunity to develop new systems or improve their product or service design to satisfy customers and fulfill their future requirements.

The main aim of case study presented in this research is intended to provide a method that assists designers in conducting sustainable design analysis. This will ensure that products are designed using sustainable customer requirements and that they will have positive environmental, economic, and social impacts whilst meeting customer requirements. The future of product and service designs depends on their ability to respond quickly to the developing and changing market demands, which are determined by the customer. This research takes on the future of sustainable design, its rising demand on the market, and its dependence on eco-friendly customers.

8. Future work

From a methodological point of view, there may be numerous sections of concern for future work. Like examining the dynamic change of other factors apart from the time perspective and the change in customer requirements over time, there are other factors that affect the customer requirements and change it toward sustainable design like technology development, societal needs, environmental problems and changes in the economy.

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