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Research article

Applying Quality Function Deployment to Green Building Design and Performance Assessment in Malaysia

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A B S T R A C T

The research paper uses the Quality Function Deployment (QFD) model to evaluate the green apartment project in Johor Bahru, Malaysia. This study involves 97 viable questionnaires given to the industry experts and potential users using the House of Quality (HOQ) tool. Through a systematic review of green building design standards and evaluation systems, the work quantifies user requirements to technical specifications and reveals essential quality attributes, including the energy efficiency rate, renewable energy use percentage, life-cycle price, and safety of materials. Main results are: the HOQ correlation matrix can exactly convert user demands into design requirements (e.g., prefabrication technologies decreasing lead time and expenses of construction), and it confirms the validity of the application of QFD in green architecture. The solutions offered were much better compared to the local markets standards in terms of energy efficiency and health measures.

1. INTRODUCTION

Due to the growing severity of global climate change and energy crisis, there has been a high level of concern about environmental protection and energy saving among people, which is setting green building as one of the central directions of the future of the construction sector [1,2]. In spite of their benefits regarding sustainability and efficiency in energy, green buildings have a low market penetration [3]. The available literature shows that green buildings maximize the use of resources, consume less energy, and have minimal environmental impact, at the same time, balance ecological, economic, and social benefits [4]. Nevertheless, in designing green buildings, there are multidisciplinary complexities involved where decision-making processes encounter high levels of uncertainty and conflicting interests- including how to satisfy both client demands and technical specifications as well as how to reconcile the lifecycle stages trade-offs [5]. These issues underline the failure of the conventional design approaches in providing systematic consideration of various stakeholders' requirements in a structured way, which requires special tools to improve the quality of the decision-making process. Subsequently, the exact interpretation of the requirements driven by the markets to technical resolutions, defining competitive strategies and satisfying customer needs has become the key point.

The most popular systematic method to achieve quality engineering, known as Quality Function Deployment (QFD), which originated in the sixties, is being implemented worldwide and has been applied to architecture and performance assessment [6-8]. Its primary basis is the use of systematic devices such as the House of Quality (HOQ) to convert customer demands to quantifiable design attributes, enhancing product quality and customer satisfaction at their origin [9,10]. In these newer applications, QFD has been applied to evaluate building projects through the support of its capability to produce demand-design parameter correlation matrices that reduce the loss of information [11]. E.g.: Triangular Fuzzy Numbers were combined with QFD to solve the dilemma of transforming client preferences into technical indicators that should be taken into consideration when planning a green hotel as suggested by the work of Zhou et al. [5]; however, the strength of QFD analysis was improved with the help of a methodology referred to as Analytic Network Process (ANP) to confirm stakeholder agreement on the rating of Malaysia Green Building Index by Ignatius et al. [12]. It can be noted that these works focus on the specificity of the QFD in terms of the matching of the functionality and sustainability requirements.

The current paper has adopted QFD as a means of integrating the user needs and requirements with the design of the product and translating the qualitative needs into quantitative measurable values through questionnaires in order to ascertain what can be improved on green building components. It is done through formulating the HOQ matrix that analyzes the design parameters and resolves the contradictions to eventually come up with a QFD-based structure that would help in optimizing the green buildings project. The solution combines both user requests and technical specifications in a creative way, removing the existing design shortcomings and providing an innovative view of sustainable architecture innovation.

The case study will be carried out on an apartment complex located 1 km on the other side of the strait that faces Singapore across Johor Bahru, Johor State, Malaysia, and can be utilized to catch both industrial and residential overflow demands of Singapore. Part of the Malaysia Iskandar Special Economic Zone, the project enjoys government measures, including less foreign equity controls and tax incentives.

The site plan follows the maximum floor area ratio (FAR) of 3.0, together with a height restriction of 120 meters, as seen in Figure 1. The complex consists of six buildings and four unit types, including tech tenant apartments, innovation office space, auditoriums, and support facilities. The interconnected design (with buildings connected by interstitial structures between residential and accelerator towers, skybridges, and subterranean passages) has great structural complexity. Massive irregular parts and multifactorial design features represent considerable difficulties in assessing the project. Important factors are: Functional Zoning: Combination of R&D, education and business areas; Structural System: Hybrid construction system with prefabricated shearing walls and steel-concrete composite beams; Sustainability Features: Solar shading fins, rainwater collection, and phase-change insulation materials. Figure 1 gives geographical information about the project.

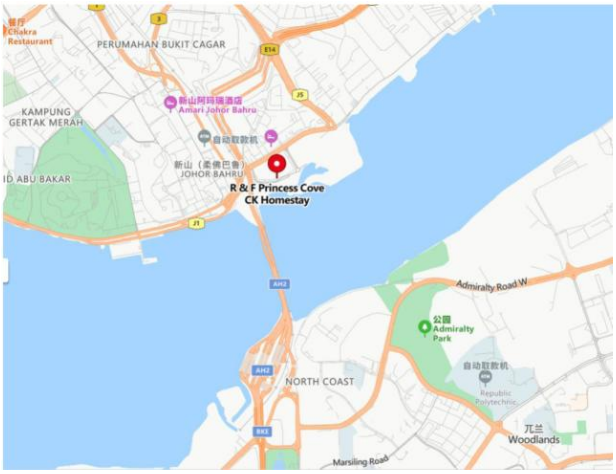

Fig. 1. Project Location.

2. CONSTRUCTION OF HOQ FOR GREEN RESIDENTIAL BUILDING DESIGN

Quality Function Deployment (QFD) is a systemic process by which user needs are incorporated into product design using transformation of qualitative demands into quantifiable indicators, making it possible to optimize designs [13,14]. One of the tools used in QFD, which is a core component, is the House of Quality (HOQ), a matrix-like structure shaped like a house with interrelated functional parts. Creation of HOQ is an essential step in order to make sure that the design of a product [15], which in this case would be a green building, does not deviate much away from client needs right from the beginning. Not only does it define clearly what customers want and how these requirements can be fulfilled, but it also helps teams to determine design contradictions, determine competitiveness in the market, and eventually develop prioritized solutions to improvement strategies.

2.1 QFD Implementation Steps

The QFD process usually comprises five stages interrelated with each other in order to convert the voice of the customer in terms of systematic action into design and production specifications. These steps are useful in green building projects to make sure that the design choices are environmentally beneficial, economically viable, and acceptable to the users. Initially, the Collection of User Requirements is the first step and one of the most important bases of QFD which consists of collecting and understanding actual user requirements and expectations (both residents, developers, regulating organizations, etc.) by using different types of market research, including questionnaires, focus group discussions, in-depth interviews, observation of the marketplace and analyzing competitors. User refers to both end-users, in the context of green buildings, but also developers, property management organizations, governmental regulatory organizations, and even residents in the nearby communities. Their interests may vary: occupants could care about indoor air quality, energy bills, comfort, daylighting, and material safety; developers could be concerned with initial investment costs, operating costs, market appeal, certification levels, and return on investment; whereas governments could be concerned about adhering to environmental regulations, sustainable development objectives, and social welfare. That is why it is essential to gather all the data to guarantee that green building designs satisfy the expectations of various stakeholders. The current research that will integrate 97 valid questionnaires by expert practitioners and potential users will offer a substantial basis of user requirements to further construct the HOQ.

The second step after gathering qualitative user requirements is the Technical Specification Development, which entails the conversion of these requirements into quantifiable and measurable technical metrics or what are referred to as Hows. The implementation of this stage entails working closely with interdisciplinary teams, including architects, engineers (structural, mechanical, electrical, HVAC), materials experts, and sustainability advisors. An illustration illustrating how an overall user requirement of high energy efficiency can be subdivided into a set of particular technical parameters includes building envelope U values, percentage of renewable energy systems integrated, type and efficiency of smart energy management systems, etc. As an instance of comfort, it might mean certain temperature levels and humidity regulation, noise limits, and natural illumination factors. These technical specifications should be clear enough so that they can be applied and checked correctly in the design and construction process.

Third, the creation of a Technical Correlation Matrix requires specifying the interrelations between various technical specifications. On any complicated product or project, e.g., a green building, changing one of the technical parameters can easily affect other parameters. They correspond to the part of the HOQ entitled, “Roof. ” As an example, the increase of the window area to increase the amount of natural daylighting could interfere with the thermal insulation behavior of a building, except when applying advanced glazing technologies. Alternatively, using prefabricated assembly technology to reduce construction times may have a positive correlation with some parameters concerning more complex structural designs, which would be efficient overall. The design team will be able to comprehend the overall implications of technical choices more effectively, resolve possible conflicts earlier in the design stage, and achieve the greatest level of synergy effects by determining these positive (complementary), negative (antagonistic), or null (irrelevant) relationships.

Fourth, it is the Critical Factor Identification step where critical technical parameters that most affect customer satisfaction are obtained through the importance weights of user requirements and the magnitude of their correlation with technical specifications. It is usually done through the calculation of an overall importance score of each technical parameter that is in the last section of the HOQ, i.e., the Floor. When the critical factors are known, the team designing the item can concentrate on using its limited resources and effort into optimizing technical fields that have the largest effect on bringing about user value and increasing the competitiveness of the product. On green building projects, this could be the improvement of energy efficiency, streamlining of renewable energy systems integration, or ensuring non-toxicity of materials, as these are often the value points that receive the highest priority during use by users. Lastly, with the help of the critical factors identified and the technical correlation matrix, the Improvement Strategy Formulation ends the QFD process, which includes developing particular improvement optimization strategies. The strategies do not only have to be technical, but they can also imply certain processes, the choice of materials, or construction methods. As an illustration, when energy efficiency has been determined to be a critical factor, one approach would be to adopt more efficient insulation materials, incorporate innovative solar photovoltaic systems, or apply smart building management systems. These strategies can be directly traced back to the original user requirements, and the result of these strategies is the enhancement of the overall quality and market performance of the green building project. QFD can ensure that every improvement activity is meaningful, based on evidence, and contributes to the overall quality and performance of the project in the market.

Table 1. Evaluation Criteria for Architectural Design Proposal.

Level 1 Criteria	Level 2 Criteria	Description
Technical Indicators	Floor Area Ratio (FAR) and Building Density	Total site FAR close to 3.0; Greening rate of Phase II is no less than 15 per cent; Building density of Phase II is not higher than 50 percent
	Coordination with Phase I Architecture	Architectural, structural, traffic flow, façade design and cultural identity consistency between Phase II and the current buildings on Phase I
	Constructability & Underground Space	Reduce construction effect on Phase I; Maximize use of underground space in terms of its commercial worth and spatial utility
	Innovation Hub & Office Demand	Leverage cluster advantages to fulfill R&D innovation, business office, and integrated training functions
	Academic Facilities & Dormitory Requirements	Accommodate teaching/training needs and student housing with foundational conditions for education industry chain integration
Commercial Indicators	Bid Quotation	Economically rational pricing compliant with design brief requirements
	Quotation Explanation	Detailed breakdown of pricing rationale, design principles, and compliance evidence
	Construction and Installation Costs	The exact estimate of construction and installation costs related to the work and MEP that are consistent with the requirements of the market and project details
	Bill of Quantities (BOQ)	Clear itemization with verified quantities, appropriate rate references, and logical pricing composition
	Price Reduction Flexibility	Clearly defined quantitative allowances for potential cost reductions

Corporate Qualifications	Design Accreditation	Valid industry certifications with qualified personnel, equipment, and technical capabilities
	Industry Reputation	Demonstrated influence and standing within the architectural/engineering sector
	Relevant Project Experience	Proven track record in comparable design, technical consultancy, or EPC projects
	Client Satisfaction	Documented client feedback and satisfaction metrics from recent projects
Social Responsibility	Green Building & Energy Efficiency	Comprehensive sustainable design strategies meeting green building certification standards (e.g., LEED, BREEAM)
	Environmental Protection	Mitigation measures for minimizing ecological impact on surrounding areas
	Campus-wide Integration	Masterplan-aligned design addressing holistic campus development needs
	Application of Four New Technologies	Implementation of innovative technologies, processes, materials, and equipment
	Risk Management Capability	Robust control mechanisms for structural safety, fire protection, civil defense, and construction risks
Stakeholder Relations	Proactive Collaboration	Demonstrated commitment to active engagement throughout the design process
	Long-term Partnership Potential	Expression of interest in establishing ongoing strategic collaboration
	Cultural Alignment	Compatibility with client's corporate culture and values
	Team Coordination Capacity	Effective internal team coordination and client-designer collaboration capabilities

In the case of green buildings, the HOQ modeling is a systematic approach to identify the key design factors based on the client's requirements. The architectural design evaluation system is the holistic integration of five dimensions of architectural design evaluation system including technical compliance (compliance with FAR, building density, and phase integration requirements), commercial rigidity (commercially acceptable bids with clear BOQ and cost analysis), corporate capabilities (valid design history and project experience), sustainability promises (eco-certification, environmental protection, and state-of-the-art technology implementation), and synergy amongst stakeholders (culture compatibility and teamwork). The balance between quantitative measures such as the Phase II greening rates of at least 15 percent with qualitative measures of innovation and the ability to survive risks is systematically maintained, prioritizing designs maximizing regulatory, functional and partnership value.

2.2 HOQ Architecture

The HOQ is a graphic device with a structure that looks like a house and it has six interrelated functional components of the major parts that have particular information and together they create a systematic format to translate customer requirements into technical specifications. Not only does this model assist in the determination of important factors in the design, but it also contributes to the consensus between multidisciplinary teams, where the voices of all the stakeholders have been effectively taken into consideration and reflected in the model [16]. The six structural elements in the HOQ operate in conjunction to convert the Voice of Customer (VOC) into the product design specifics.

As shown in figure 2, the HOQ comprises six sections. Left Wall (WHATs Matrix): This part is the foundation of the HOQ and it identifies what customers want and need and the extent to which they prioritize them. When discussing green buildings, these WHATs have been determined through surveys of experts in the field and prospective consumers, comprising expectations about energy efficiency, indoor environmental quality, healthy materials, water saving and maintenance cost. These requirements are normally qualitative and need to be translated into measurable parameters as required by 1-5 ranking of importance (1=less important, 5=important). The formula to calculate user requirement weight is:

$$h_i = \frac{\sum_{j=1}^{k} y_{ij}}{5k} \quad (1)$$

where hi denotes the normalized weight of the i-th customer specification; is the score assigned by the j-th respondent to the i-th customer specification; and k is the overall number of respondents.

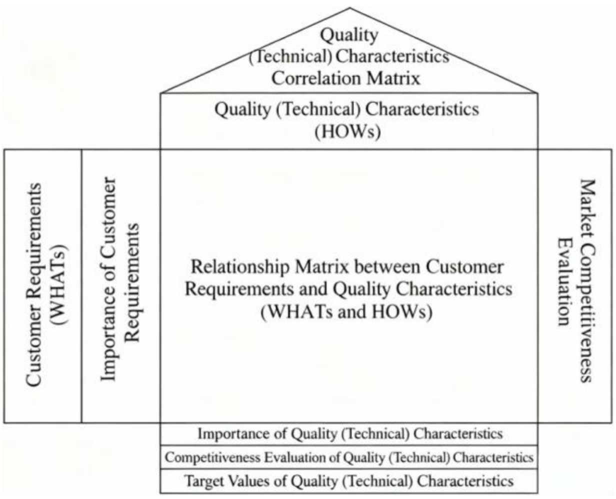

Fig. 2. Components and Structure of the House of Quality (HOQ).

Ceiling (HOWs Matrix): The given section provides a list of the technical requirements, also known as HOWs, to be fulfilled to meet customer needs stated in the Left Wall. These are design variables and engineering qualities that can be controlled by the product design team, like photovoltaic coverage ratio, thermal insulating properties of the building envelope (U-value), smart lighting systems, or the efficiency ratio of high-efficiency HVAC systems [17]. The selection and prioritization of such energy-related technical parameters may involve multiple and potentially conflicting criteria, for which multi-criteria decision-making approaches have been widely applied [18]. They are specific measures of how to implement customer requirements and need to be feasible, measurable, and comprehensible to engineers and designers.

Cover (CORR- HOWs): Such is a triangular matrix that is applied to measure the interdependence of various technical properties that are important in the alignment of design processes and addressing possible conflicts. E.g., increasing the window size to increase the availability of natural daylight may reduce thermal insulation performance of a building, hence establishing a negative correlation among the variables of daylighting and thermal insulation. The correlations are usually shown by symbols: = (strong positive, score 5), * (moderate positive, score 3), (weak positive, score 1), blank (no relation, score 0).

The Room (Requirement-Specification Matrix): It is the essence of the HOQ, which is the cross-mapping matrix that makes the linkage of customer requirements (WHATs) with technical specifications (HOWs). Every cell in this matrix represents how strong the relationship of both a particular customer requirement and a technical parameter is, commonly expressed by means of qualitative signals and the appropriate numerical ratings (e.g., 9=high correlation, 3=medium, 1=low, 0=none), either based on expert evaluation or historical information. Here is where this matrix plays its crucial role in the capacity of QFD to turn the voice of the customer into technical speech by quantifying the degree to which each technical parameter contributes to satisfying the needs of customers.

Right Wall (Market Competitiveness): The section can be used to assess the competitiveness of the existing product or design proposition in the market environment and identify the desired level of improvements in the performance. It consists of the present consumer satisfaction, competition standards, and the targeted improvement objectives that are usually measured on a scale of one to five. In the present research, with the help of the analysis of information on 97 valid questionnaires (40 experts and 57 potential buyers), it is possible to estimate the position of the green building project on the market. Market competitiveness (Mi) is determined by:

$$M_i = \frac{T_i}{S_i} \quad (2)$$

Here, Ti represents the target level of the demand of the ith object, and Si represents its current satisfaction. When Mi is greater than 1, it means that improvements need to be made, and the greater the Mi, the greater the need for improvement.

The floor (HOQs Output): In this section, the output of the HOQ is presented, which focuses on the technical parameters depending on the data of the previous parts. It is usually performed by determining the weighted importance of a technical parameter as a product of a weight assigned to the customer requirement in the Left Wall and a strength of demand-specification correlation in the Room, and taking their sum. Also, the Floor contains the list of target performance thresholds (e.g., reducing energy consumption by 20 percent, renewable energy self-sufficiency of 65 percent), technical feasibility evaluations that steer the distribution of resources, and further design choices.

2.3 Green Building HOQ Matrix Construction Process and Data Collection

(1) User Requirement Identification and Collection

The detailed listing of all possible user requirements and their correct gathering are considered to be the foundation of the HOQ matrix construction. In the present research, a structured questionnaire has been used to measure user value on different attributes of green building, including energy efficiency, indoor environmental quality, and material safety. Each requirement was evaluated using a 5-point Likert scale (1 being the least important and 5 being critical). The information has been collected by 97 valid respondents who were quite diverse, such as 40 industry specialists (architects, engineers, and sustainability specialists), whose observations were made through the lens of technical and strategic viewpoints, and by 57 potential users who are the representatives of the target demographic of customers, who directly expressed end-user attitudes. After the data collection, a statistical evaluation of all questionnaire answers was done to obtain the initial importance ratings in regard to each user requirement, which formed the starting point of the HOQ's Left Wall and identified some preliminary agreement on essential stakeholders.

(2) Technical Parameter Development and Definition

Another important point in the development of HOQ matrices is the translation of qualitative user needs into certain measurable technical parameters (the HOWs). The above-mentioned process was used to develop the green building-specific technical parameter set in this study:

The first element of the transformation process was based on the tight cooperation between an interdisciplinary group of experts. This was a group of experts that included top specialists in architectural design, structural design, mechanical and electrical systems, material science, and certification of sustainable buildings so that no technical aspect of green buildings would have been missed. After several rounds of workshops and brainstorming, the team reviewed and thoroughly explained the raw requirements collected through user surveys and attempted to put them into plain and workable language of engineering. As an example, when it was reported by users that they expect to have a healthy indoor environment, experts transformed it into various technical indicators that could be realistically achieved, including selecting low-Volatile Organic Compound (VOC) materials, incorporating highly efficient air filtration systems, and implementing a real-time monitoring system to control indoor CO_2 levels.

Following up on the above, due to their individual professional expertise and broad industry rules and regulations, the team methodically translated the theoretical consumer needs into diverse quantitative and manageable technical specifications. As an illustration, user requirements to achieve high energy efficiency were quantified as metrics, including average U-value of the building envelope, optimizing the ratio of windows per wall, capacity and coverage rate of renewable energy systems (such as solar photovoltaics), response speed and efficiency of smart energy management systems. User issues about a comfortable indoor environment were also detailed to specific temperature control limits, methods used to manage humidity, limiting the level of background noise and maximizing natural daylighting coefficients. Besides being a specific way to satisfy customers needs, these parameters are also clear technical instructions that should be followed during the next stage of the optimization process of design.

(3) Determination of Requirement-Technical Parameter Correlation Strength

The creation of the so-called "Room" (Requirement-Specification Matrix) is a central stage in the HOQ process because it is supposed to help to quantify the level of mutual impact between user requirements and technical parameters in a systematic manner. In order to make this assessment objective and authoritative, as stated above, this research involved the named group of experts in the industry who participated actively through several rounds of intensive discussion and consensus conference to fulfill the task. At these conferences, expert groups carefully examined all possible pairs of the type of user requirements-technical parameters, analyzing the relationship between them with one another in depth using their extensive experience and understanding of green building developments.

The given correlation strength was measured with the help of this 5-level scale, which is an exact numerical measurement: a score of 5 indicated strong correlation, which signifies the technical parameter has a significant role in addressing that particular user requirement; 3 meant moderate correlation, which means that it has a significant bearing on the satisfaction of the user requirement; 1 indicated weak correlation or some non-pivotal impact; and 0 indicated lack of correlation, i.e., no correlation existed at all. Such a precise quantification process led to the formation of the ultimate numerical matrix of the HOQ Room section. The matrix shows how each technical parameter specifically adds to the fulfillment of different user requirements and, more importantly, delivers the necessary information needed to determine later on the cumulative significance of the technical parameters; therefore, the quantitative character of the analysis is ensured.

(4) Assessment of Interrelationship between Technical Parameters

The HOQ matrix section named Roof is the one that tries to identify and quantify the relationships between different technical parameters that are considered useful in terms of matching the design process with possible conflicts, as well as identifying synergistic relationships. Similarly, experts also had an important part in evaluating the same in the case of the Room section, where they studied all possible pairs of technical parameters to find out if two technical parameters could interact positively, negatively, or not at all.

The inter-relationships were measured in terms of these criteria: +1 meant synergy and this was when an improvement in one technical parameter led to the success or optimization of another thus producing a win-win situation; -1 means contradiction and this was because an increase in one parameter may cause the failure of another parameter or have negative effects on it and so it requires design compromises and coordination; and 0 means no inter-relationships that is that there was no inter-pair interaction between the two technical parameters at all. The design team acquired the opportunity to predict possible areas of conflict and actively look into the integrated solutions by identifying and measuring such complicated relations between parameters at the initial stage of the design process. Not only does it help to maximize the overall plan of the design, eliminating expensive and lengthy changes in the future due to unexpected contradictions, but above all, it ensures inter-departmental interaction and communication, which eventually guarantees that the final design of the green structure will provide the best possible balance of all the performance characteristics.

3. RESULT AND DISCUSSION

Using the stated methodology and the information gathered during a large scale questionnaires survey we have developed a House of Quality (HOQ) matrix of our green residential project, as shown in Figure 3.

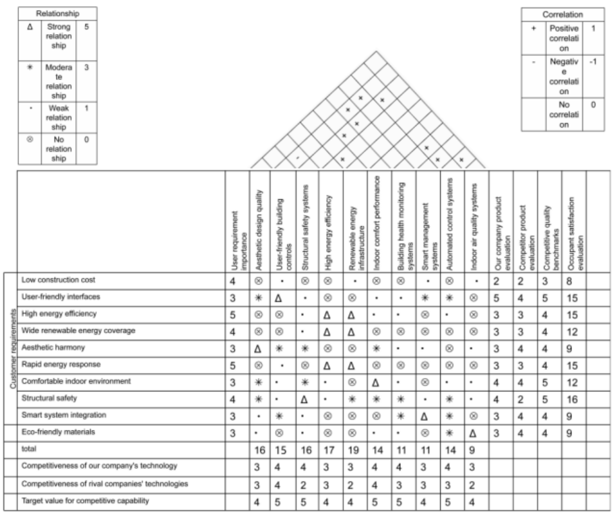

Fig. 3. House of Quality (HOQ) Matrix for the Green Residential Building Project.

This chapter is based on the comprehensively developed HOQ matrix that appears in Figure 3 and explores the quality characteristics in detail that are directly impacting user satisfaction, environmental friendliness, and commerciality of the green residential project. With a quantitative measure and interrelationship analysis of these qualities, priority areas of improvement could be determined to allow more specific approaches to improving quality.

3.1 Analysis of Quality Characteristics in Green Residential Buildings

(1) User Requirements Priorities and Weights (Left Wall Section)

In the House of Quality (HOQ), under the concept of Left Wall, customer requirements (WHATs) and their ratings of importance are represented as User requirement importance ratings on a 1-5 scale with 5 being the most important.

The priority of user requirements indicated by the HOQ Left Wall provides very clear clues concerning what stakeholders consider essential in green residential structures. The two highest scores are given to "High energy efficiency" and "Rapid energy response" with an importance rating of 5. It suggests quite firmly that consumers are no longer interested in saving energy, but they want the energy system to be very reactive, which might indicate either smart home energy management, stable emergency power sources, or dynamic load adjustment. This is completely consistent with the focus of the energy performance aspect being one of the top user issues mentioned in the abstract of the paper. Next are "Low cost of construction," "High renewable energy coverage," and "Safety of structure," each with an importance score of 4. The indicators point to the fact that, despite the fact that environmental responsibility and safety hold great worth, economic feasibility of the project, especially for first-time investments, continues to play a vital role among prospective users. Also, there is a strong preference towards the wide application of renewable energy sources and the basic requirement of safety and stability of the structure. Important, yet secondary to the central energy performance, cost, and safety areas, were such categories as: User-friendly interfaces, Aesthetic harmony, Comfortable indoor environment, Smart system integration, Eco-friendly materials.

The major issue in this context that needs to be taken into consideration is that there is a dual focus on the highest possible energy performance, which is confirmed by the fact that two of the three main focuses are to reach the maximal degree of energy efficiency, and the speed of energy response. It implies that the design and execution of the project energy system will be faced with a massive amount of pressure to deliver its performance in these two areas, namely, the minimization of consumption and promptness in reacting to the demand. At the same time, the low cost of construction is also commonly in conflict with the initial cost of advanced green building technologies. This implies the necessity to find a balance and develop effective cost control strategies that do not negatively impact the critical performance that should be taken into account as a fundamental contradiction throughout the design and construction process.

(2) Customer Requirement-Technical Parameter Relationship Matrix (Room Section)

The strength of the relationships between customer requirements (WHATs) and technical parameters (HOWs) is measured in the form of numbers in the "Room" segment of the HOQ. The symbols mean numerical values: △=5 (high correlation), *=3 (medium correlation), ●=1 (low correlation) and ⊗=0 (absence of correlation).

The correlation matrix of the Room section depicts a thorough picture of how customer needs are converted into specific technical requirements. It is worth noting that the top priority customers needs, namely, High energy efficiency and Rapid energy response, have high correlations (score 5) with other technical parameters. The correlation of High energy efficiency is solidly associated with the technical parameter of High energy efficiency (as an indicator of inherent energy saving design) and Renewable energy infrastructure, which unambiguously confirms that the ultimate purpose of optimizing building performance and incorporating large-scale clean energy solutions is both objectives. On one hand, the correlation of the technical parameter of High energy efficiency, Smart management systems as well as Automated control systems, with the demand of Rapid energy response is evident, indicating that to be able to react quickly to energy changes, not only the foundations of energy efficient design but also the advanced smart and automated systems are needed. It is interesting in that the correlation between Low construction cost and Smart management systems, and Automated control systems is only average (score 3). This suggests that although intelligent systems may provide long term operational savings, it is not considered to provide much benefit to reducing initial construction costs, or are seen as being more of a value-add that can justify a particular initial outlay. As predicted, user-friendly interfaces are highly correlated to user-friendly building controls, emphasizing the significance of user-friendly controls in manipulating the controls of building systems, whereas eco-friendly materials are highly correlated with indoor air quality systems only, implying that their most important perceived value in the environment is through enhancing indoor environmental health.

A significant issue that can be derived out of this extensive analysis is the intricacy and interconnectedness of technologies involved in the fulfillment of high-priority user needs, especially in the field of energy. The project should adopt a multi-level approach in order to meet the dual high energy efficiency and fast energy response requirements and invest in the best possible building envelope performance, powerful renewable energy infrastructure, and state-of-the-art intelligent management and automation systems. This requires a perfect integration among diverse fields of engineering. Also, the interaction of Low construction cost with advanced, usually more costly, technological solutions necessary to achieve better energy and smart performances creates a significant cost-benefit challenge, which needs to be carefully planned and innovative materials or construction techniques used.

(3) Important Technical Parameters and their Scores (Floor Section)

The section labeled as 0 Floor generally provides a calculation of the Total Score of each technical parameter, which is its general significance in meeting the needs of customers. To calculate this score, you need to add up the multiplication between the importance rating of any of your customer requirements and the correlation power between it and the given technical parameter. These whole scores are illustrated in the given HOQ picture.

As carefully computed and demonstrated in the section titled Floor, the ranking of technical parameters based on their overall contribution to addressing the various needs of users is clearly represented by the Total Score. The most significant technical parameter is undoubtedly "Renewable energy infrastructure" with the highest score of 19. This highlights the fact that even though the users explicitly value "High energy efficiency" and "Rapid energy response" the most effective way to obtain them, to attain maximum overall consumer satisfaction, is through the comprehensive and wide-ranging incorporation of the renewable energy sources. The technical parameter of itself, High energy efficiency, earns 17 points, confirming the initial importance of the design and performance based on an intrinsic energy-saving building structure. Both the aesthetic design quality and structural safety systems score a high score of 16 points, placing them in 3rd place, indicating strongly that the building goes far beyond functionality but has an important role in terms of its visual aesthetics and basic safety, which are not considered secondary. On the contrary, Indoor air quality systems obtained the lowest score (9), followed by Building health monitoring systems and smart management systems (each 11). Although these systems cannot be understated as part of a holistic green building, their lower scores imply that they do not have an immediate effect on the main drivers of satisfaction, and that the top-tier drivers of satisfaction are energy, aesthetics, and safety.

The key problem caused by such a strong prioritization is the necessity to strategically and significantly distribute resources on the enhancement of renewable energy integration and base-level energy efficiency. Since they have a significant impact on user satisfaction, these areas should be prioritized in terms of design, technology choice, and investment. Yet at the same time, it is impossible to ignore the fact that the most-valued aesthetic qualities and structural strength are important factors both in terms of market attractiveness and in terms of the confidence of potential occupants. The main challenge here, therefore, is developing a holistic design concept that optimizes the highest energy performance determinants at the same time with a delicate incorporation of aesthetic excellence and unshakable structural safety, frequently under a set budget limit.

4. CONCLUSION

The current research has effectively created a Quality Function Deployment (QFD) based framework that would allow setting up systematic alignment between green building design and sustainability requirements and user preferences. The creation of the research House of Quality (HOQ) model, which takes into consideration the demand, technology, and cost factors, showed the serious issues and opportunities of green apartment projects in Malaysia to reach high sustainability rates, and it also demonstrated a list of basic ways of improvement.

The study indicated that energy efficiency and use of renewable energy are the highest quality attributes in terms of the point of view of the users. Nevertheless, there is a common so-called performance gap in the current green buildings, along with the complexity of incorporating renewable energy sources, which are serious obstacles to reach in the market. At the same time, there is a significant disparity between the increased initial prices of green buildings and the customer preference for life-cycle cost-effectiveness, which causes divided market acceptance. Moreover, material safety, indoor air quality, and important health performance indicators are also affected by the performance constraints of eco-materials and lack of consumer confidence. To remedy these problems, the present research suggests various specific approaches to quality improvement, such as optimization of energy efficiency by means of envelope improvements, smart glazing solutions, and real-time control systems; increase of renewable energy integration using the photovoltaic arrays of massive sizes, hybrid storage solutions, and policy incentives; minimization of costs efficiently by prefabricated construction, purchase in bulk, and carbon financing instruments; provision of health and safety with rigorous material requirements, an effective air filter of high-efficiency, and structural IoT solutions.

The methodology driven by QFD successfully alleviates the inconsistency between the theoretical requirements of green building certification schemes and the realities of project implementation. Not only does it offer a tool for making decisions based on data, but it also provides the opportunity of having a system approach when considering commerciality of a project while guaranteeing good environmental impact. This paper shows that optimal green building design solutions may be very much better than market-local benchmarks in energy use and health indices. The given study gives developers a feasible structure of strategy as it allows them to be competitive in the market and achieve the long-term value of their business alongside the accomplishment of sustainable development objectives. Additional studies might continue to broaden the scope of the HOQ framework to incorporate other wider regional climate differences and circular economy measures, thus providing more general guidance on how to keep improving continuously in the green building industry.

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