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Identification of Maintenance Related Issues as Noise Strategy in Building Design

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Graphical abstract

Abstract

Design of a building focuses on meeting basic needs and cost. It lacks in performance evaluation of the building which is normally translated as the ease of building operation and maintenance. Robust Engineering (RE) method has the ability for building design to focus on clients' expectation. It improves building performance as it significantly influences product performance in use. High engineered quality is achieved by evaluating the interaction between user environment or noise with control factors. The aim of this research is to identify user environment which is also known as noise during building use and important consideration for better building performance. The research design in this study included an expert panel interview and a questionnaire based survey. Respondents of the expert panel interview are professionals who have experience in building design and maintenance. The questionnaire survey was conducted to identify current design focus, main problems during building operation and key factors to improve maintenance related needs of a building. Findings suggest that improving maintenance related needs in building design seeks collaborative design effort in sharing and translating design information, efficient use of information and effective analysis method, focus on product performance on user environment, sustainable use of resources as an integrated system with low waste generation and development of designer competency. Noise in building design consists of space planning, material selection, equipment selection and integration, and control factor(s) to suit the authorities' approval and supply chain support consideration.

Keywords: Robust engineering method in building design; noise in building design; high maintainability building design

Abstrak

Reka bentuk bangunan memberi tumpuan kepada memenuhi keperluan asas dan kos. Ia kurang menumpukan kepada penilaian prestasi bangunan yang biasanya diterjemahkan dengan mudahnya operasi harian dan kebolehsenggaraan bangunan. Kaedah Kejuruteraan Robust mempunyai keupayaan untuk membolehkan reka bentuk bangunan memenuhi jangkaan pelanggan. Ia memperbaiki prestasi bangunan dengan mempengaruhi prestasi bangunan semasa beroperasi. Dengan menilai interaksi antara persekitaran pengguna atau hingar dengan faktor kawalan, kualiti kejuruteraan yang tinggi dapat dicapai. Kajian ini bertujuan untuk mengenal pasti persekitaran pengguna yang dikenali sebagai hingar semasa bangunan beroperasi dan faktor penting untuk prestasi bangunan yang baik. Reka bentuk kajian ini meliputi temu bual panel pakar dan kaji selidik. Responden kepada temu bual panel pakar mempunyai pengalaman luas dalam reka bentuk dan senggaraan bangunan. Kaji selidik dijalankan untuk mengenal pasti tumpuan utama reka bentuk bangunan, masalah utama operasi bangunan dan faktor utama untuk memperbaiki kebolehsenggaraan bangunan. Dapatan kajian menunjukkan reka bentuk secara kerjasama dalam berkongsi dan menterjemahkan maklumat reka bentuk, penggunaaan maklumat yang efisien, penggunaan kaedah yang efektif, fokus kepada prestasi produk dalam persekitaran pengguna, penggunaan sumber secara bersepadu dan pembangunan kompetensi pereka bentuk mampu meningkatkan kebolehsenggaraan dalam reka bentuk bangunan. Hingar dalam reka bentuk bangunan merangkumi perancangan ruang, pemilihan bahan, pemilihan dan integrasi peralatan, manakala faktor kawalan adalah kelulusan pihak berkuasa dan sokongan rantaian bekalan.

Kata kunci: Kaedah kejuruteraan Robust untuk reka bentuk bangunan; hingar dalam reka bentuk bangunan; reka bentuk bangunan dengan kebolehsenggaraan yang tinggi

■1.0 INTRODUCTION

The conservative view of building design is ensuring compliance to law for safety and meeting the cost agreed by the client [1]. It satisfies the basic needs of building with low consideration in adding value to design result. While pressure to speed up production in terms of design and construction increases, the clients also expect high-quality design, ease of building maintenance tasks, and stable cost in use. Therefore a more efficient design method is needed. A design with low maintenance related consideration has a significant effect on building performance. As the need becomes more complex, the building design approach also needs to change its focus. It must focus on building performance with high engineered quality [2]. There are two types of quality, namely customer quality and engineered quality [3–5]. The customer quality is what customers want while the engineered quality is the good performance and reliability of the building design.

The manufacturing product development approach has gained improvement in terms of product design. It has become the main reference to learn and apply the product design technique in the construction industry. A method such as Robust Engineering (RE) approach in manufacturing has been proven to improve the product's engineered quality and performance. Amongst important considerations in design to ensure product performance is the ability to identify the noise affecting a product while in use. Building performance is often being criticised as not meeting users' expectation for quality during occupancy. Maintenance related complaints during day-to-day use involved noise which affects building performance as clients do not want noise as it is affecting the cost and their well-being.

The aim of this research is to identify maintenance related issues during building where noise during building design is investigated and considered as an important element for better building performance.

■2.0 ROBUST ENGINEERING METHOD IN BUILDING DESIGN

2.1 Robust Engineering Method

RE is an optimisation strategy in the design of engineered products [3–5] before the products are released to users to avoid loss to the society. RE evaluates performance of products, materials and equipment [3–14]. These improvements aim at improvising the needed characteristics and simultaneously lessening the number of defects by studying the key variables controlling the procedures or design to yield the best results. RE Method is based on five key principles as follows [3], [4]:

- Measurement of function using energy transformation,
- Taking advantage of interactions between control and noise factors,
- Use of orthogonal arrays and signal to noise ratios,
- Two step optimisation, and
- Tolerance design using quality loss functions and online quality engineering.

The first two principles focus on planning while the remaining three principles focus on application of mechanics and statistical tools in product development. All man-made engineering system use energy transformations to convert input energy into specific, intended output responses to deliver specific results sought by clients. In every engineered system there exist some form of ideal relationship between the input signal (M) and the output (y). Robust design seeks to reach this ideal state referred to as the design's ideal function [3]. This is shown in Figure 1.

The planning stage needs a multidimensional diagnosis system [4] where the control variables are considered as design space in which all the control variables are identified as controlling the design. Controls variables are any design boundaries of a system that allow an engineer to specify nominal values and preserve cost effectively. The input signal, expected output and noise where the client uses the space for interaction between control variables and noise factors are evaluated to improve performance. The noise factors comprise of three types, namely environment (client's usage condition, temperature, humidity, surrounding subsystem), ageing or wear (change of property over time, effect of cycling, deterioration over time, the durability of a subsystem) and manufacturing variability (variability within tolerances, assembly variation, batch to batch variation, piece to piece variation) [3–5]. Achieving robustness is to take advantage of the interaction between design space and the client use space at the upstream stage of product development [3].

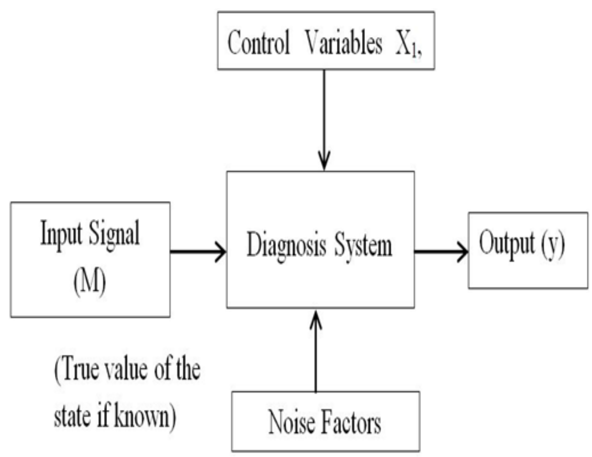

Figure 1 Multidimensional diagnosis system

2.2 Building Design as Manufacturing Product Development

Current design approach in construction is seen as inefficient in producing building designs with high operational performance. Building performance is often being criticised as not meeting users' expectation for building quality and users' expectation at the use stage. Design of a building gives strong emphasis on meeting basic needs and cost. The building design result is also seen as lacking in evaluating performance of the building which is normally translated as the ease of building operation and maintenance. There are many reports aiming to improve the construction industry productivity by promoting the need to improve construction product development to meet users' satisfaction at the maintenance and operational stages [15–19]. Researchers emphasised time related element in design where maintenance related consideration must be considered at the design stage [20–29]. Focus on the clients' needs with high engineered quality product and development of designer's competency are seen as a driver of change to improve the industry. In manufacturing, improvement in terms of product design, make and assembly have been realised by adapting better production philosophy. Adapting the building design as manufacturing is with the assumption that it will espouse the same benefit to the construction industry as it has done in the manufacturing industry. The similarities between the manufacturing and construction industries are as follows [30–34]:

- Produce physical engineered products and utilised by the users,
- Utilising raw materials and assembly of parts to produce final products,
- Repetition of processes of design and construction stage,
- High cost of reworks, and
- Large data management between organisation and disciplines.

2.3 Maintenance Related Issues as a Noise Strategy for Building Design

All buildings designs are predictions and all predictions can be wrong. Where a plan is based on a prediction, a strategy is designed to encompass unforeseeably changing condition created by changing environment or noise [25]. Construction product is a 'one-off' large made-to-order product, while manufacturing product is produced in mass production. A construction product has a longer design life up to 100 years compared to a manufacturing product that has a shorter design life within 10 to 15 years. The long design life of a building has the influence of the law and its future needs.

The design consideration of shorter design life may not change throughout its design life but the longer the design life makes it much harder to predict the relevancy of design consideration for a construction product as it may change over time. It is important to identify the main concern of building operator which normally affects users' satisfaction. These design considerations are identified as control factors and noise which interact with one another and affects the performance of the building. As noise changes throughout the use of the building, the performance of the building is predicted to eventually decrease.

As a building is a construction product, it has a long design life. The maintenance related issues during the day-to-day operation is considered as noise in a building design. It is important for the design process to be able to incorporate the building maintainability requirements by identifying the lesson learned and operational problems during building operation which may be categorised as noise in building design. By identifying noise and the interaction with the control factors, a better building design with optimum performance can be achieved. The noise here represents the building's day-to-day concerns which affect performance of a building. In a scenario-buffered building, noise is taken into consideration and incorporated in scenario planning stage as shown in Figure 2 to produce a built-for-change design [25].

Consequently, maintainability is a simplicity where a system can be maintained to optimise the use of space and equipment with minimum interruption to users of the building [35]. Optimising use of space refers to space planning in design stage where the analysis and design of spatial and occupancy requirements, maintenance and logistic route for installation and moving in and out of large equipment including, but not limited to space layouts and final planning.

In RE method, the space planning is referred to user environment noise (client's usage, temperature, humidity, surrounding subsystem). In the context of product design, the main goal of material selection is to minimise cost while meeting product performance goals. It also involves in system integration where it involves the bringing together of the component subsystems into one system and ensuring that the subsystems function together as a system. In RE method, it refers to noise due to ageing and manufacturing variability. All of these interact with the control factors where typically the control factors for design space comply and conform to the requirements and standards and the supply chain support.

Figure 3 shows the factors that are considered by designers. The main concern consists of space planning, material selection, equipment selection and system integration. Building design uses an intuitive procedure to suit the authorities' approval. An approach such as the RE, is a better tool to complement the decision making in building designs. The main emphasis that reflects the RE aim is to ensure minimal or no loss to the users and society in terms of reducing defective product. The efficient simulation and confirmation test reduce the possibility of failure during building use. It also helps the clients to make more accurate decisions when selecting a design solution.

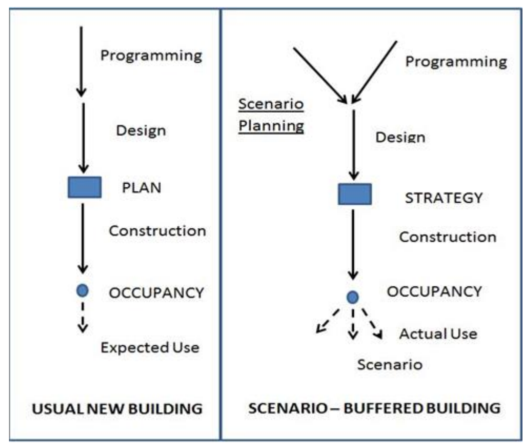

Figure 2 Scenario-buffered building [25]

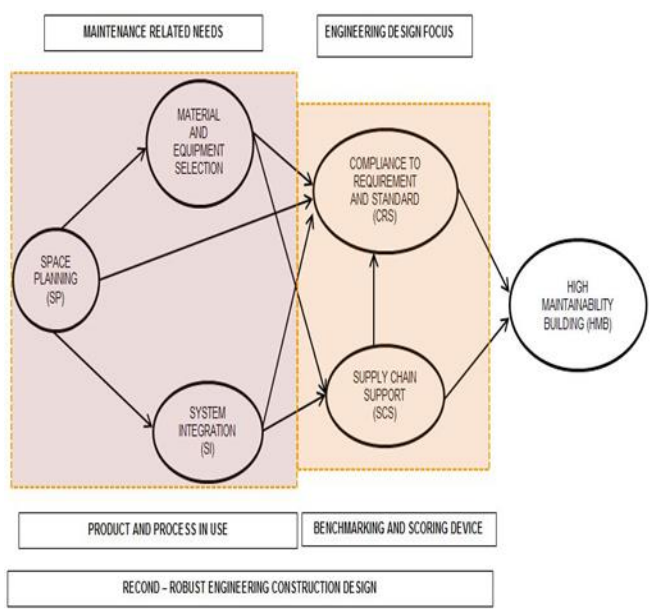

Figure 3 Building design main consideration [2]

■3.0 METHODOLOGY

The data collection methods in this research are: an expert panel interview using a prepared semi structured interview questions followed by a questionnaire survey to identify the current design focus, main problems during building operation and key variables to improve maintenance related needs of the building. The respondents of the expert panel interview are professional design engineers and building operators who have experience in building design and building maintenance. Data were collected from interview questions as shown in Table 1.

Table 1 Expert panel interview questions

THEME	QUESTIONS
INFORMATION AND DATA DURING HANDOVER OF FACILITY	What are the information needed by facility management during facility hand over? Are there any specific guidelines during handover of facility?
MAINTENANCE REQUIREMENT CONSIDERATION	In your design process do you address the maintenance requirement? To what extent, the current design approach considers the maintenance requirement? Are there any established guidelines to enable building designers to incorporate maintenance requirements during design stage? How does the current design approach utilise lessons learned from previous design solution to cater for any improvement or input from maintenance experience?
MAINTENANCE DURING OPERATION	What is the major component of building facilities that requires constant maintenance? What are the key maintenance issues in building operation? Are most building maintenance works due to poor design? Is there any specific method to measure maintenance requirement at design stage?
WISH LIST DURING OPERATION TO IMPROVE BUILDING MAINTENANCE	How should current design practice integrate with the building operation requirement? What are the challenges in producing a design that requires less maintenance/maintenance free?
INFORMATION FOR BUILDING MAINTENANCE DURING DESIGN PHASE	What do information designer s use during design for maintainability requirement? How do the clients describe their needs in terms of maintenance of the propose facility? Is there any communication made between the designers with building maintenance personnel of the client's organisation during the design process?
EVALUATION OF DESIGN VS. MAINTENANCE	Are there any design optimisation strategies being used at the design stage to address the issues of maintenance currently? What are the key maintenance issues in building operation that must be considered at the design stage?
ENABLER FOR IMPROVEMENT	What is the possibility of adopting the manufacturing design process in building design? Are designers able to adopt new techniques in producing building design? What are the challenges in changing the current design method to focus on maintenance? What are the criteria used by designers in specifying materials and equipment for building during design?

The interview was conducted from February, 2013 until March, 2013. The responses to the interview questions asked in the interviews were recorded and transcribed verbatim. The interview started by first presenting the aims of the research, followed by questions and a discussion of the responses from the design engineers and building operators from selected organisations.

In the questionnaire survey, two population frames comprising the public sector and the private consulting firms were selected. The selected public sector was based on the nature of the organisation core tasks which are executing building design and building maintenance operation. The private sectors that were chosen were mainly design firms which have extensive experience in building design. The population of interest is defined as building designers including architects, civil, mechanical and electrical engineers, quantity surveyors, and client technical and maintenance engineers. Data collection was conducted from early April, 2013 to end of May, 2013. The questionnaires were handed out to the design engineers and collected immediately after they were completed.

Section A of the questionnaire was designed to reflect the profile of the organisation and the respondents. Section B focused on the current design process setbacks and maintenance related complaints received from the building users [36]. The complaints that were listed are categorised as follows:

- Safety: Fire protection, structural constraints, and security.
- Design quality: Functional layout, choice of equipment and choice of materials.
- Maintenance: Ease of cleaning, ease of repair or replacement, and access to clean area.
- Building user comfort: Air circulation, indoor air quality, humidity control, lighting, heat loss or heat gain, human traffic, vertical transportation, and noise protection.
- Building services: Clean water, wastewater disposal, and communication system.

■4.0 RESULTS AND DISCUSSION

4.1 Questionnaire Survey Response Rate and Respondents' Profile and Organisations

Of the 250 questionnaires sent, 111 responses were returned representing an overall rate of 44.4%. The responses were checked for completeness and coded for data analysis. The public sector represented 54.1% of responses while private sector represented 45.9% of responses. All respondents were involved in design tasks with 67% of respondents rated they as competent in building maintenance. In terms of work experience, 5.4% have under 5 years of experience, 15.3% have 6 to 10 years of experience, 20.7 % have 11 to 15 years of experience, and 24.3% have more than 21 years of experience. Field of discipline comprises of Architect 1.8%, Civil Engineer 27%, Mechanical Engineer 36%, Electrical Engineer 34.2% and Others (Project Managers and Quantity Surveyor) 0.9%. The service the respondents' organisations provided are: Architectural design 23.4%, Civil engineering design 57.7%, and Mechanical engineering design 72. %, Electrical engineering designs 73.9%, Building equipment design, 53.3%, Infrastructure design 58.6%, and Project Management 12.6%.

4.2 Maintenance Consideration in Current Building Design Process

There is a general agreement by the expert panel that there are no specific tools or methods used to measure maintainability of a building project. Building design has assumed that the current code of practice has considered the maintenance needed. The code of practice incorporates maintenance related considerations based from experience and presents the consideration as a specification and manual. In the questionnaire survey, respondents were asked for their views on the current design focus for maintenance consideration. Table 2 tabulates respondents' agreement and disagreement of of setbacks in the current design in capturing maintenance related needs in design. The comparison is also made by the findings from the expert panel interview [2]. 78.4% of respondents disagreed with the statement that the current design process gives high emphasis on the maintenance related needs and 75.7% of respondents agreed that there is low consideration of maintenance related needs in the current design process.

The expert panel also stressed that the current design process does not focus on maintenance related needs but the main focus is compliance to clients' need, regulation by authorities and capital cost ceiling. Almost all respondents acknowledged that there are no formal procedures for designers to incorporate maintenance requirements and it is based entirely on the experience of the designers. To improve designs, a structured approach that focuses on meeting the users' expectation in terms of maintenance related consideration is being highlighted. An approach such as the RE is a better tool to complement the decision making in building designs. The main emphasis that reflects the RE aim is to ensure minimal or no loss to the users and society in terms of reducing defective products. The efficient simulation and confirmation test reduce the possibility of failure during building use. It also helps the clients to make more accurate decisions when selecting a design solution.

The lack in standard guidelines for integration and selection of materials contributed to low maintenance related needs consideration in the current design process. The majority of the respondents agreed that maintenance related needs need improvement to ensure better design outcome. Figure 4 describes the enablers to improve maintenance related needs in design.

Table 2 S etbacks of current design focus

Statements	**Expert Panel View**	**Responses (N=111)**	
		Disagreed	**Agreed**
The current building design process gives high emphasis on the maintenance related needs.	Disagreed	**78.4**	21.6
The current building design process gives low emphasis on the maintenance related needs.	Agreed	24.3	**75.7**
There is no formal procedure for designers to incorporate maintenance requirement in building design.	Agreed	8.1	**91.9**
There is no formal procedure used to translate the maintenance needs into design specifications.	Agreed	7.2	**92.8**
The maintenance needs are incorporated in design based on the experience of the designers.	Agreed	3.6	**96.4**
There are standard guidelines for the integration of maintenance related needs in the design stage.	Disagreed	**70.3**	29.7
There are standard guidelines for materials and equipment selection criteria in the design stage.	Disagreed	**64**	36
Incorporating maintenance need is not satisfactory and must be improved.	Agreed	5.4	**94.6**

Figure 4 Enablers to improve building maintainability

4.3 Maintenance Related Complaints from Building Users

To identify the noise or user main concerns during building operation, designers should seek and collect comments made by the users including building maintenance firms. As shown in Figure 5, the maintenance category where most actions taken towards the complaints are repairs and replacement (88%, Rank 1), access for cleaning 77.5%, Rank 4) and Cleaning (37.8%, Rank 6). This shows that at the operational stage, the space planning, and material and equipment selection are of great importance [23], [25], [26], [29], [36–41]. These factors are also considered as noise during operation of building. For design quality element, it is found that: choice of material (86.5%) is at Rank 2, choice of equipment (82.9%) is at Rank 3 and functional layout (38.7%) is at Rank 5. Again the importance of space planning and material and equipment selection is important to building users. While Safety, Building Users' Comfort and Building Services were in the range of 34.2% to 8.1%. This consideration is also important as it interacts with the building users to enable sustainable and conducive environment. It reflects the need for system integration to enhance building performance.

Design is a complex decision making stage. There are many factors to consider and some trade-offs made to suit limit cost. Figure 6 shows the factors that are important during building day-to-day operation. The main concerns consist of space planning, material selection, equipment selection and integration. Building design uses an intuitive procedure to suit the authorities' approval. RE is a better tool to complement the decision making in building designs. The main emphasis that reflects the RE aim is to ensure small or no loss to the users and society with lessening defective product. The efficient simulation and confirmation test lessen the possibility of failure during building use.

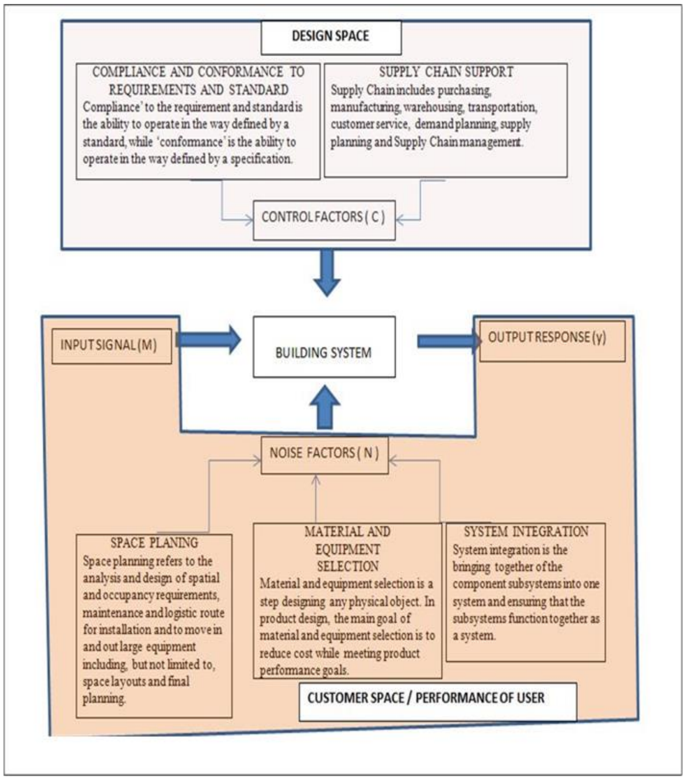

Figure 5 P-Diagramme for building systems design

■5.0 CONCLUSION

Maintenance related issues during the day-to-day use of the building is considered as noise which is effecting the building performance. It is affecting the operational cost and well-being of its occupants. The finding indicates that noise in building design is categorised as space planning, material and equipment selection, and building services and system integration. The controlling factors of building design is compliant to rule ad regulation or clients' needs and the consideration of supply chain support. This interaction is as shown in Figure 6. Taking advantage of the interaction between control factors and the identified noise, a better building design which satisfies users' expectation at operation stage can be achieved.

In the RE method for building design, the space planning refers to user environment noise (client's usage, temperature, humidity, surrounding subsystem). In the context of product design, the main goal of material selection is to minimise cost while meeting product performance goals. It also involves in system integration where it is the bringing together of the component subsystems into one system and ensuring that the subsystems function together as a system. All of these factors, interact with the control factors which typically the control factors for design space consisting the compliance and conformance to requirements and standard and the supply chain support.

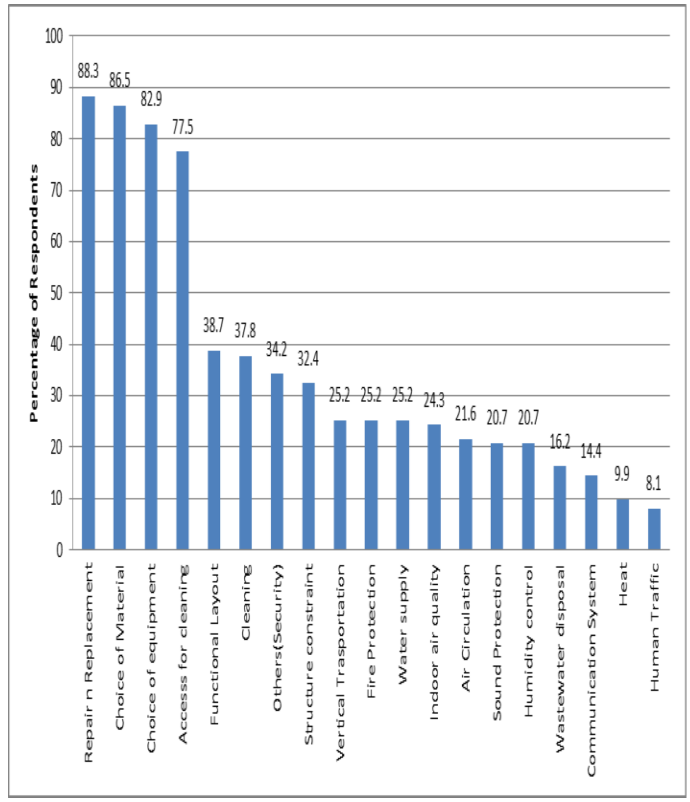

Figure 6 Complaints received from building users

Figure 3 shows the factors that are considered by the designers. The main concerns consist of space planning, material selection, equipment selection and system integration. Building design uses an intuitive procedure to suit the authorities' approval. This study proposes the RE method as a better tool to complement the decision making in building designs. The main emphasis that reflects the RE aim is to ensure minimal or no loss to the users and society in terms of reducing defective product. The efficient simulation and confirmation test reduce the possibility of failure during building use. It also helps the clients to make more accurate decisions when selecting a design solution.

It is recommended that further investigation be conducted on the enablers in improving building design and noise in building design as given in the proposed structural models in Figures 3 and 4.

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