

A Model for Assessing the Quality of Mass-Constructed Residential Buildings in Iran Based on an Intelligent Fuzzy Inference System

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Abstract

Quality in the construction industry is a function of a wide range of factors among which, those depending on the residents' viewpoint are of a high importance. This study presents a model for evaluating the performance of mass-constructed residential buildings in Iran in terms of satisfaction of residents, based on an Adaptive Neuro-Fuzzy Inference System (ANFIS), and aims to provide applicable results. The measurement of the quality of buildings and expectations of the occupants is done through collecting and analyzing data using questionnaires. Results show that the satisfaction level with regard to security and privacy in buildings are of a higher importance than other aspects of the buildings and the most important factors determining satisfaction were the type, location and aesthetic appearance of the buildings, which must be considered in designing buildings. Access to energy resources in buildings with regard to resource allocation by government needs to be modified, too.

Keywords:

Mass-constructed residential buildings, Quality assessment, Iran, Adaptive Neuro-Fuzzy Inference System (ANFIS), Security and privacy

Introduction

Since ancient times, human being was looking for a place to live in. This is still a fact today, and people need a building

as a house to carry out a wide range of activities and leisure there. Therefore, the main purpose of building houses, as stated in Ibem et al. research paper [1], is "to provide occupants with conducive, safe, comfortable, healthy and secured indoor environment to carry out different kinds of activities ranging from work, study, leisure and family life to social interactions". Designing, planning, constructing and managing buildings lead to the achievement of the mentioned objectives, but this should be done considering the required standards and specifications introduced by professionals and experts who know what people need and expect [1].

Quality of a building is closely related to its architecture to enhance its design quality and satisfy the requirements and expectations of its owner or users [2]. Unfortunately, in most of the cases buildings do not meet the users' needs and expectations perfectly. This may have several reasons. One of the main reasons to name is the lack of adequate knowledge with regard to the residents' changing needs and preferences, which should be considered by designers, constructors and maintainers in this field. Some researches such as [3,4] have confirmed theses. Their results indicated that residents may not always be satisfied with the performance of their buildings due to the nonconformity of the standards and specifications with the changing needs and expectations of the users. The consequences of such a dissatisfaction are revealed in building related illness and 'sick building syndrome' [5], and the increase in the desire for remodeling or modifications or abandonment of completed buildings [6], which may cause waste of energy and sometimes even damage to the building envelope components and the surrounding environment [7].

To explore and understand users' needs, expectations and aspirations through regular performance evaluation is one

of the ways to improve the overall performance of buildings as suggested by some researches [8,6]. Due to this suggestion, building performance evaluation (BPE) can be used to constantly examine the extent to which buildings are effective and efficient in meeting the needs and expectations of the users [6]. Among other functions, BPE relates clients' goals and performance criteria set by experts to the measurable effects of buildings on the users and surrounding environment [9]. It also provides basic information on users' needs, preferences and satisfaction [10]. Therefore, BPE primarily seeks to improve the quality of design, construction and management of buildings and by extension promotes sustainable built environment.

This study will bridge the gap in the literature on user satisfaction and performance of mass-constructed residential buildings, concentrating on Iran. The results would extend our understanding of the key elements that could be manipulated to improve residents' satisfaction with, and the performance of residential buildings in housing schemes. Taking this into mind, the remaining part of the paper is organized as follows. Section 2 reviews the related literature regarding quality of buildings and consumers' satisfaction. Data collection and research methodology is discussed in section 3, and results and discussion is presented in section 4. Section 5 concludes the paper and suggests future work.

Literature Review

Residents have various expectations from the performance of their building. Existing studies [1,8,11-17] focus on the general performance of public housing in meeting occupants' needs and expectations. From these studies, it is established that the physical characteristics of residential buildings have a significant influence on occupants' satisfaction with their residential environment.

"Satisfaction is a measure of the difference between the actual and expected performance of products or services in meeting users' needs and expectations from the users' or consumers' perspective during or after a consumption experience." This means that if the performance of a product or service meets users' or customers' needs and expectations, the user or customer is said to be satisfied with the product and/or service, and vice versa [1,18].

Satisfaction studies cut across a wide range of disciplines in the management and social sciences as well as the built environment. Even some studies regarding building environment have considered residents' satisfaction; such as a study in Northern Europe, which investigated the interaction between preferences, neighborhood design and walking [19], and a study conducted in China, which compared dwelling conditions, daily activities, and individual satisfaction in traditional neighborhoods and in the redeveloped New Siheyuan areas [20].

Generally speaking, satisfaction is a subjective evaluation of the performance of products or services in meeting the needs and expectations of users or customers [1,21]. Buildings like any other products are designed and constructed with lots of expectations by customers, profes-

sionals, users and the society. To customers, buildings require enormous capital investments and are expected to bring returns on investment, while to professionals (e.g. architects, builders and engineers), buildings are products of their creativity and imaginative thinking. Gupta and Chandiwalla (2010) [22] added that the evaluation of performance of residential environment has traditionally been based either on physical monitoring or user satisfaction surveys. This is principally because users give their views and/or feelings about buildings-in-use based on their experience and interactions with buildings as compared to the views of professionals who design and construct buildings and never use them [10,23]. It is observed that in the course of exploring residential or housing satisfaction, some researchers adopted satisfaction surveys to examine residents' satisfaction with the dwelling units in public housing estates in the different countries.

An indicator is also developed by the Construction Industry Council (CIC) in the UK, which considers three fields of quality: functionality, build quality, and impact of building in measuring the quality of design embodied in the buildings through feedback and perception of all stakeholders involved in the production and use of buildings [24]. With inspiration from this Design Quality Indicator (DQI), a study was conducted by Suratkon et.al in 2016 to identify indicators for measuring the satisfaction towards design quality of buildings and to evaluate the suitability of the indicators for application in the context of Malaysian construction industry [24].

Besides, BPE is important in understanding the actual performance of buildings in meeting the various expectations of the different stakeholders as compared to predicted performance, and the efficiency of building procurement process. Therefore, it would help evaluating consumers' satisfaction. Depending on the rationale and objective of the research, it is clear that BPE may be intended for the formulation and implementation of government policies, or the development of new theories or research tools or the dissemination of information on the performance of building spaces and fabrics to professionals, contractors and material manufacturers in the building industry as well as to the public [1].

Literature review shows that in the last few decades, much progress has been made in developing different BPE tools and approaches [6]. The main categories of approaches to BPE, which have been presented in more detail in Khair et al. (2012) [25], include those focusing on the (i) functional suitability of buildings that is space utilization, physical condition, safety and statutory requirements; (ii) quality assessment of buildings; (iii) serviceability of building with respect to occupants' needs and facilities provided; (iv) environmental performance in terms of indoor environmental quality, air quality, intrusion, control, appearance and lighting; (v) energy consumption and indoor air quality; (vi) user satisfaction with the design and construction of and services in building; (vii) post occupancy evaluation of technical, functional and behavioral aspect of buildings.

In order to capture the feelings and expectations of all



categories of users in the course of evaluating the performance of buildings, Kian et al. (2001) [5] and Kim et al. (2005) [6] on one hand suggested the adoption of six BPIs, namely; spatial (functional) comfort, indoor air quality, visual comfort, thermal comfort, acoustic comfort and building integrity (structural and material performance). On the other hand, they argued that since BPE is based on the concept of users' experience, BPIs should be based on parameters related to thermal comfort such as heating, ventilation and air-conditioning; illumination and visual comfort; occupants' satisfaction and behavior as well as physiological and psychological comfort of users.

From the above, a number of inferences can be made. First, BPE can follow different approaches and diverse tools and indicators can be used for it. Second, the expectations of users and the community with respects to buildings are varied and can be measured in terms of performance indicators. Finally, different approaches to BPE, and the tools and indicators used in this regard, contribute to policy, practice and research, when they focus on issues related to users' satisfaction, and the sustainability of buildings, and the surrounding physical and socio-economic environment. It is on this premise that the conceptual framework of this study is based on the notion that residents' satisfaction with housing units measured as building performance indicators and determined by the users' characteristics and the physical, spatial, locational, service and economic attributes of buildings. A new model will be suggested for evaluating the quality of residential buildings in Iran considering this framework.

Methodology and Data

The aim of the present study is to design and provide a new system for evaluating the quality of mass-constructed residential buildings in Iran. This study is based on user satisfaction surveys and was targeted at Iranian occupants of mass-constructed residential buildings. A total of 274 housing units were identified for the low, middle and high-income earners, and structured questionnaires were used for eliciting responses from the informants during several visits to the housing units. The informants were household heads. Conducting an analytical evaluation of the research literature, content analysis, which is a widely used qualitative research technique was applied. Current applications of content analysis show three distinct approaches: conventional, directed, or summative. In this study, a combination of conventional and summative approaches were used. The questionnaire used was designed by the researchers and included questions on the personal profiles of the respondents as well as their satisfaction with regard to the physical, spatial, location and aesthetic aspects and cost attributes of their buildings and also air quality, energy and other utilities in the buildings. The items compatible with Iran situation was adopted and a new factor containing 3 sub-factors under the title of "Building automation and control systems was added" as a

contribution in this paper.

The questions provided in the questionnaire were used to quantify the attitudes of the residents towards the selected 26 building attributes through asking the respondents to rank their satisfaction.

Using the SPSS software, data derived from the survey were subjected to Table 1.

Data obtained was used for building a Neuro-Fuzzy system and knowledge about the system inputs and outputs, and rules derived from the literature were obtained through library study.

Fuzzy Systems and Neural-Networks are natural complementary tools in building intelligent systems. While neural networks are low-level computational structures that perform well when dealing with raw data, fuzzy logic deals with reasoning on a higher level. However, fuzzy systems lack the ability to learn and cannot adjust themselves. A Neuro-Fuzzy System is, in fact, a Neural Network that is functionally equivalent to a fuzzy inference model.

An ANFIS system can incorporate fuzzy if-then rules and also, provide fine-tuning of the membership function according to a desired input-output data pair. A first order Sugeno fuzzy model is used as a means of modeling fuzzy rules into desired outputs. The forward pass adjusts the neuron consequents, layer-by-layer, to minimize the error.

Once it has reached the output of the last layer, the backward pass begins and the antecedents are updated as the consequents are held constant. However, the difference (between the ANFIS and an ANN) that needs to be considered when creating a prediction system is in the selection of model parameters.

To use the ANFIS model in MATLAB, the user defines the number of inputs; the number of membership functions (MFs) and their type/shape; and the number of training epochs. Changing even one of these parameters by just a small amount can be the difference between a system that appears to be not working at all and a system that produces desired results.

The specific advantages of ANFIS over the two parts of this hybrid system are:

- ANFIS uses the neural network's ability to classify data and find patterns.
- It develops a fuzzy expert system that is more transparent to the user and also less likely to produce memorization errors than a neural network.
- It keeps the advantages of a fuzzy expert system, while removing (or at least reducing) the need for an expert.

However, the problem with the ANFIS design is that a large amount of training data is required to develop an accurate system.

The validity of the content analysis is the consensus of the researcher on each of the factors and their associated indexes. The greater the settlement amount, the higher the reliability and validity of research.



Table 1- Factor analysis of 26 building attributes investigated

Building attributes	Factor weight	Total weight
<i>Factor 1: type, location and aesthetic appearance</i>		3.966
Number of bedrooms	0.7	
Building type	0.733	
Design of bath and toilet facilities	0.680	
Type of materials used in the construction of building	0.667	
Location of building in the housing estate	0.532	
Aesthetic appearance of building	0.654	
<i>Factor 2: Sizes of internal spaces</i>		1.824
Sizes of living rooms	0.681	
Sizes of bedrooms in the house	0.521	
Sizes of cooking and storage spaces	0.622	
<i>Factor 3: Illumination, thermal and visual comfort</i>		3.334
Quality of natural lighting in bedrooms	0.524	
Natural lighting in kitchen	0.5	
Quality of air in bedrooms	0.514	
Natural lighting in living rooms	0.577	
Quality of air in living/dining spaces	0.559	
Thermal comfort in the building	0.504	
Privacy in the building	0.734	
<i>Factor 4: Security and protection</i>		2.466
Protection against noise pollution	0.645	
Protection against dampness in the building	0.431	
Protection against insects and dangerous animals	0.343	
Security measures in the building	0.577	
Fire safety measures in the building	0.470	
<i>Factor 5: Water and electricity supply</i>		1.011
Electrical services in the building	0.553	
Water supply and in the building	0.458	
<i>Factor 6: Building automation and control systems</i>		1.381
Optimized control heating /cooling in the building	0.446	
Optimized control ventilation and air conditioning (HVAC system)	0.454	
Optimized control lighting	0.481	

In this study, a Neuro-Fuzzy Inference System is used in order to predict the quality of mass-constructed residential buildings in Iran based on the residences' satisfaction and point of view. The selected factors were obtained after a wide literature review and content analysis. In order to provide the fuzzy model, 7 fuzzy systems are applied, 6 of which are used in order to extract fuzzified results of each factor, and finally an overall Fuzzy System is applied which receives the fuzzified results of the 6 factors and provides the fuzzy level of building quality after fuzzifying them.

Methodology and Data

Based on the selected factors, suitable questionnaires were designed, validated and given to the population. Data collection was conducted through questionnaires and in 2 groups (actual situation and forecast situation). The first group consists of the population whose information is

considered for the neural system as the current situation after fuzzy inference. This population contains 274 groups of selected buildings in different regions of Iran. The second group consists of fuzzy system experts, fuzzy results inferred from the point of views of whom are considered as training data for the Neural Network.

It is obvious that the data of the first group was applied for reasonable inference from the perspective of residents. The data of the questionnaires of this group was first normalized and then used in 6 groups as the inputs of Sugeno Fuzzy Inference System. (Table 2)

The obtained results were again used as the inputs of the final Fuzzy Inference System to determine the level of quality from the residents' point of view. The resulting output of this system is 60.8% which shows the satisfaction level of the residents from the quality of buildings in Iran in actual situation. The analysis diagram of the output changes based on the changes in the input parameters of the system, and the output of the system in actual situation are



illustrated in Figures 3 and 4, respectively.

The experts' opinions which are based on the recent situation and the domestic environment can provide a suitable guide for adaptive priority of factors in Iran. Presented results from the experts' questionnaires announce a set of feasible weighting values applied to fuzzy toolbox. It outlines the priority issues. It is important to study the opinions of experts from different fields on a common platform. Therefore, expertise with respect to three fields is involved in the process of deciding the relevant weights: architects & professionals, government, and academia &

professors.

This study sent out 24 copies to investigative experts, and received back 20 copies, which gives an obtainable rate of 95%. After filtering out the null questionnaires, there were 12 expertise copies belonging to the valid questionnaires. 9 sets of data were selected for training the system.

At this stage, the data obtained from the second group, i.e. experts, was used. In fact, this data was entered in 9 sets, using suitable training coefficients as training data to the Neuro-Fuzzy System, based on the previous system (Table 3).

Table 2- Inputs of Sugeno Fuzzy Inference System

factor 1	[0.7 0.733 0.68 0.667 0.532 0.654]	output :	0.695
factor 2	[0.681 0.521 0.622]	output :	0.597
factor 3	[0.524 0.5 0.514 0.577 0.559 0.503 0.734]	output :	0.617
factor 4	[0.645 0.431 0.343 0.577 0.47]	output :	0.491
factor 5	[0.553 0.458]	output :	0.503
factor 6	[0.446 0.454 0.636]	output :	0.521

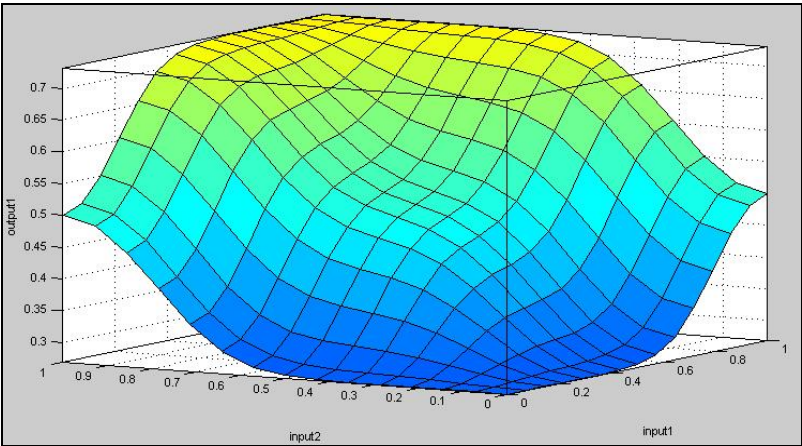


Figure 3- Analysis diagram of the output changes based on the changes in the input parameters in actual situation

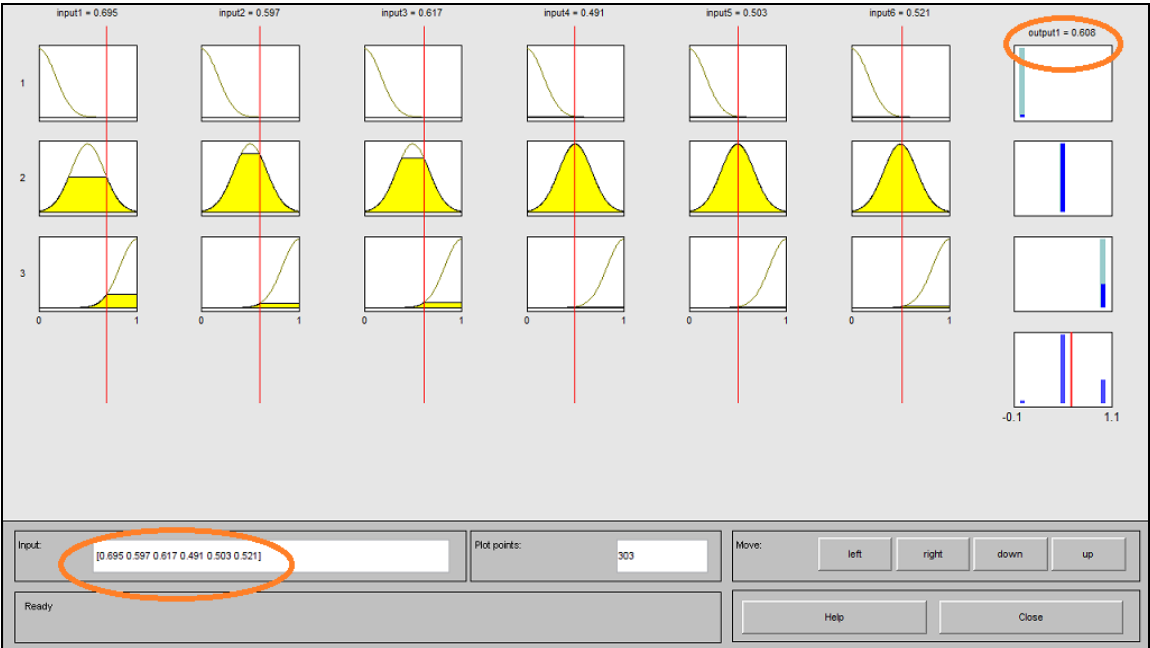


Figure 4- The output of the system in actual situations

The ANFIS model structure is shown in Figure 5. Applying 30 neurons, the optimized train was reached in the 15th epochs, and training was stopped. The output of the Fuzzy System in this stage was 61.5% which indicates the predicted level of quality from the residents’ satisfaction point of view, with the beliefs of the experts, which were provided through computational theories and logic in

forecast situation. Training and learning steps were done, and reaching the optimal point, training was stopped. The output of the ANFIS in a forecasted situation is illustrated in figure 10. For the validation process, 7 Neuro-Fuzzy Systems were evaluated based on validation methods. The diagram of NFIS validation is presented in Figure 11.

Table 3- Training data sets and factors

training factor	data sets of training					
0.56	0.581	0.563	0.743	0.701	0.802	0.650
0.67	0.432	0.455	0.678	0.770	0.798	0.567
0.84	0.480	0.526	0.763	0.697	0.789	0.539
0.67	0.590	0.654	0.645	0.763	0.764	0.592
0.88	0.553	0.532	0.679	0.694	0.810	0.575
0.68	0.423	0.494	0.612	0.794	0.762	0.602
0.97	0.501	0.472	0.721	0.787	0.832	0.546
0.63	0.498	0.456	0.703	0.659	0.791	0.498
0.43	0.439	0.515	0.643	0.705	0.726	0.571

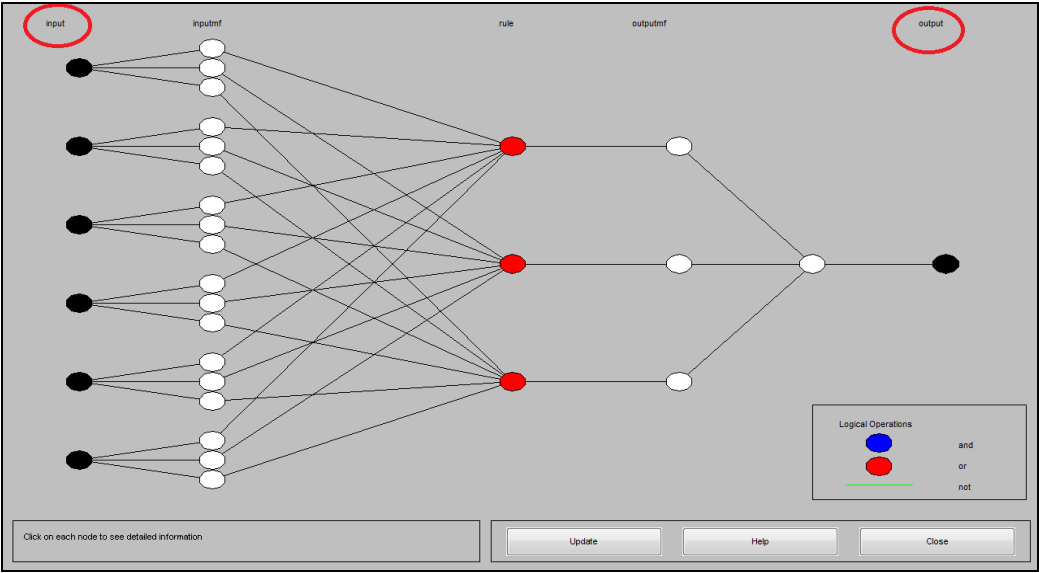


Figure 5- ANFIS model structure

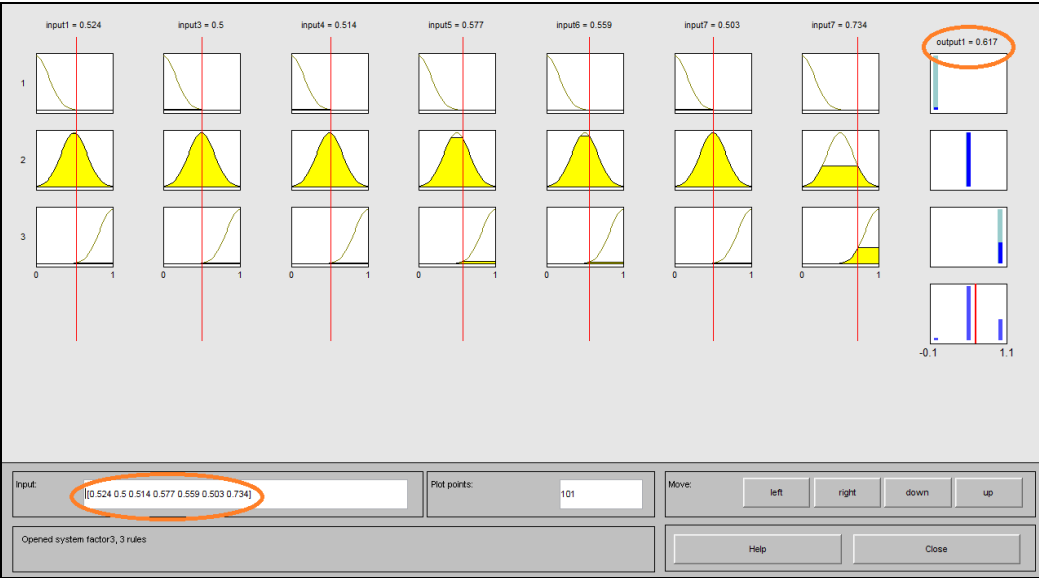


Figure 10- The output of the system in a forecasted situation



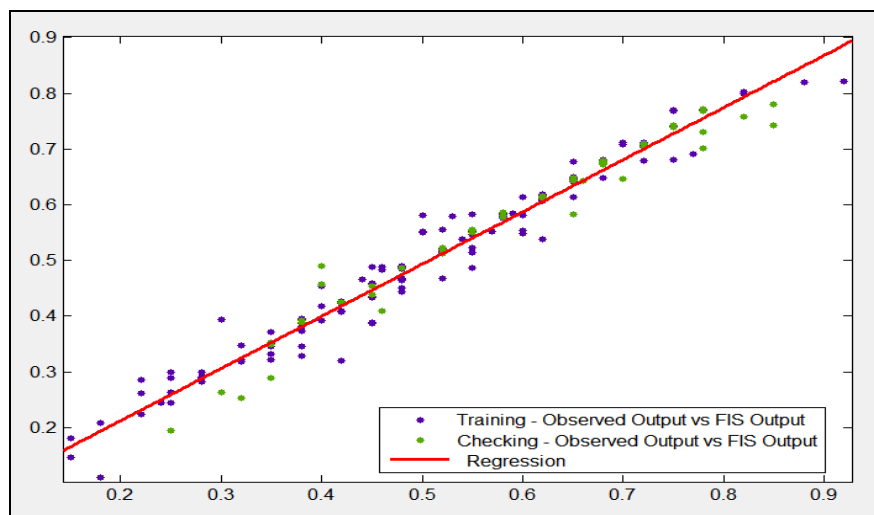


Figure 11- The diagram of NFIS validation process

Conclusion and Future Work

Residents have various expectations from the performance of their buildings. Therefore, the quality of buildings is important, as it affects the residents' satisfaction. Satisfaction is a subjective evaluation of the performance of products or services in meeting the needs and expectations of users or customers. Buildings like any other products are designed and constructed with lots of expectations by customers, professionals, users and the society.

In this study qualitative content analysis method was used and buildings quality assessment factors were studied and extracted from the literature. Using data gathered from a number of buildings residents, fuzzy inference system was designed and trained through an ANFIS.

This system has a satisfactory validation and can be relied due to the application of real data obtained from the residents. The main advantage of this system is its ability to identify strengths and weaknesses of the quality of buildings from the point of view of the residents' satisfaction. Through its learning capability, this system can receive new data and do further validation and training.

Based on the results of this study, the most important factor from the perspective of the residents is among the sub-branches of "privacy in the building", which is of the sub-sets of the 3rd factor and has a high impact on their satisfaction. But among the main factors, "type, location and aesthetic appearance" has the highest weight. Dissatisfaction of the residents from the suitable and required accessibility to the energy resources in the buildings, together with the government policies, emphasizes on the importance of the application of renewable energies in the buildings. Besides, based on dissatisfaction of the residents from the sustainability of the buildings while happening an earthquake, insurance policies for the quality of the buildings may help Construction Technical Certificate of the buildings in increasing the satisfaction of residents in these cases.

During the research process, many ideas came to mind but

there was no opportunity for considering them. Hence, the following recommendations are noted for future research:

- Constructing an integrated database, special for the buildings constructed in a specific region in order to ranking and better selecting influential factors on the quality, considering the culture and the need of each region in a way that the comments of the design engineers and regulatory experts and the concerned municipality can be continuously imposed on it.
- Connecting the fuzzy inference system to the mentioned database in order to get real-time information and analysis reports of the quality situation.
- Using simulation and evolutionary algorithms to analyze and simulate steps to implement quality improvements in buildings.
- Combining neural networks and genetic algorithms to design optimal schema of the building quality assessment.
- Combining fuzzy logic, neural networks and genetic algorithms to generate an intelligent system which is able to continually offer suggestions to improve the quality of buildings.

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