International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-5 Issue-3, February 2016

Assessment of Building Architecture Design Parameters by Applying Fuzzy Logic Concepts

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Abstract*— The field of Building Architecture and Design is considered as multidisciplinary science with a very important dimension as 'Art'. Architecture and design requires more artistic aptitude then engineering. As far as engineering and science are concerned, phenomenological paradigms are sufficient. However, need to explore new approaches as far as Art and Architecture are concerned. In architecture we make perceptions on the bases of knowledge and experience. Recently, Fuzzy Logic has been among new scientific paradigms to assess the architecture and Design quality, which actually differ or vary person to person. The research focuses on scope of application of fuzzy logic concepts and theory on architecture and design quality assessment. Architectural design quality assessment may consider as science with full of soft and flexible variables. In such situations, assessment on the subject in fuzzy logic terms plays the essential role.

Keywords: Architecture Attributes, Comfort, Fuzzy Logic etc.

I. INTRODUCTION

When we ask, what is Architecture? We receive so many reply based on understanding, perception and experience from professional and common man. As we know architecture is a multidisciplinary science, so architecture design should be dealt with the necessary information from various relevant fields. The quality assessment of architectural design (AD) is based upon various attributes like function, comfort, safety, aesthetics, inclusion of natural elements, circulation, volume / shape of the space etc. Largely we assess design qualitatively on certain parameters, which are soft and flexible in nature, as explained above. According to one of the explanation quality can be defined as the gap between client's expectations and received services and if expectations go beyond the function, the result would be client's dissatisfaction. Quality is a complicated class with different levels and related factors [1].

II. WHAT IS FUZZY LOGIC

Fuzzy logic was introduced by an American Professor *Asgar Lotfi Zadeh*, when he presented a paper on 'fuzzy sets' [2], which has been used for stating imprecise concepts. So, it can be used for explaining many human expressions or feeling [3], or may be opinion about qualitative aspects. The most important difference of fuzzy collections and classical collection is actually, the way of connecting a member with the community.

Manuscript published on 28 February 2016.
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In classical collections a factor can be a member of a community or not, while in fuzzy collections we can use the membership level [2]. In traditional or classical or crisp set logic a thing can be 0 (Zero) or 1 (One), but in fuzzy logic or continuous set each statement can be assumed a value between 0 (Zero) & 1 (One) and this depends on the level of each member which gains in terms of its attachments. Fuzzy collection eliminates the sophistication by destroying strike limit of member division, as changing from membership to non-membership seems gradually rather than being sudden [4]. The elements of fuzzy sets not only represent true (1) or false (0) value but represents the 'Degree of Truth' or 'Degree of falseness' for each input. Fuzzy logic is a form of artificial intelligence (AI); therefore, it would be considered a subset of AI. Since it is performing a form of decision making, it can be included as a member of the AI.

Representation of Fuzzy Set 'A':

$$A = \{(x_1, \mu_A(x_1), (x_2, \mu_A(x_2), \ldots\ldots\ldots\ldots, x_n, \mu_A(x_n)\}$$

X_1, X_2,……., X_n are members of set 'A' & X_n is associated with 'Fuzzy Index' or 'Fuzzy Membership' $\mu_A(x_n)$.

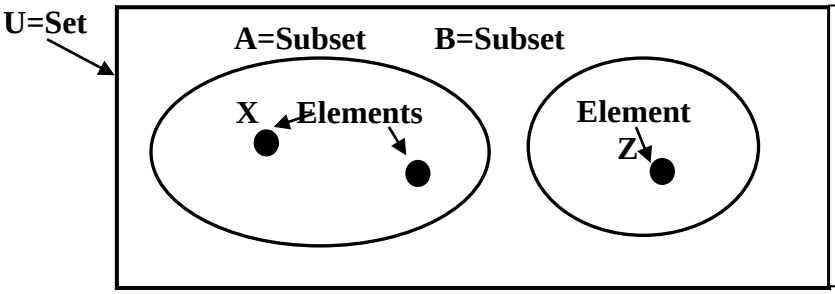
Alternative representation of Fuzzy set 'A':

$$A = \left\{\frac{\mu A(x1)}{x1}, \frac{\mu A(x2)}{x2}, \ldots\ldots\ldots\ldots, \frac{\mu A(xn)}{xn}\right\}$$

So, Traditional or Classical or Crisp set values [0, 1] and Fuzzy set values [0, 0.1, 0.2, 0.25, 0.3, 0.375,…., 0.9, 1.0]

III. CRISP SET Vs. FUZZY SET

In crisp set theory, a very precise` boundary is there to determine whether an element belongs to a set or not. The membership value in favour of the truthness of belongingness of an element/ attributes is considered as 1 or 0. For example, in a given set 'A' this function assign a value $\mu_A(x)$ to every $x \in X$ such that $\mu_A(x) = 1$ if $x \in A$, and $\mu_A(x) = 0$ if $x \notin A$.



Membership Value of elements of subset 'A'	Membership Value of elements of subset 'B'
$\mu_A(x) = 1$	$\mu_B(x) = 0$
$\mu_A(y) = 1$	$\mu_B(y) = 0$
$\mu_A(z) = 0$	$\mu_B(z) = 1$

Fig. 1: Crisp Set (subset of universal set) 'A', 'B' and elements 'x', 'y' and 'z' of Universal Set 'U'.[11]

The crisp characteristic function can be generalized such that the values assigned to the elements of the universal set fall within a specified range [0, 1] and indicate the membership grade of these elements in the set. There is no clear boundary in between set 'A' and its universal set 'U' and thus we cannot draw it. Such a function is called membership function and the set defined as fuzzy set. The membership function for fuzzy set can take any value from the closed interval [0, 1] instead of either 0 or 1 like crisp set [7]. Fuzzy set 'A' is defined as the set of ordered pair $A = \{ (x_1, \mu_A(x_1)), (x_2, \mu_A(x_2)), \ldots\ldots, (x_n, \mu_A(x_n)) \}$, where $\mu_A(x)$ is the grade of membership of element x in set 'A'. Greater the $\mu_A(x)$, greater is the truthness of the statement that element x belongs to set 'A' [2].

Example : A set X = {5, 9, 16, 24, 30, 50, 65}, whose elements denotes the number of candidates for the interview. The no. of vacant posts are 05. Set Y consists of the fuzzy set 'Less no. of candidates for the interview', fuzzy set 'Y' can be shown as Y = {(5, 0.98), (9, 0.6), (16, 0.22), (24, 0.18), (30, 0.12), (50, 0.09), (65, 0.01)}. The grades of membership 0.98, 0.6, 0.22, 0.18, 0.12, 0.09, 0.01 are subjectively determined and indicate the probability of selection of candidate i.e. 'strength or weightage or truthness' of membership of individual elements in fuzzy set 'Y'.

(Truthness of the statement) $\propto \mu_A(x)$ 'Grade of Membership'

A. MEMBERSHIP FUNCTION:

Membership function are used in the fuzzification and defuzzification steps of a fuzzy logic system (FLS), to map the non-fuzzy input values to fuzzy linguistic terms and vice versa. A membership function is used to quantify a linguistic terms. An important characteristic of FLS is that a numerical value does not have to be fuzzified using only one membership function. In other words, a value can belong to multiple sets at the same time.

B. FUZZY LINGUISTIC OR VERBAL VARIABLES:

An algebraic variable takes numbers as value while a linguistic variable takes 'Words' or 'Sentences' as value. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural languages, instead of numerical values. [2], [10]

Example: Let 'X' be a linguistic variable with label architectural '**Comfort**' or '**Aesthetics**', if the **fuzzy set** comfort and Aesthetics denoted as 'C_f' and 'A_s' respectively then,

C_f = [uncomfortable, less comfortable, comfortable, very comfortable]

A_s = [awful, ugly, normal, good, awesome]

Linguistic Variable	Comfort [C_f]	Aesthetics [A_s]
Linguistic Value	uncomfortable, less comfortable, comfortable, very comfortable	awful, ugly, normal, good, awesome
Membership Function (μ)	$\mu_{uncomfortable}$ to $\mu_{very\ comfortable}$	μ_{awful} to $\mu_{awesome}$

Here, Comfort or Aesthetics is the base variable which is also called **'Universe of Discourse'**. Each item in this fuzzy set is a fuzzy linguistic value for the variable 'X'.

IV. RELEVENCE OF STUDY / RESEARCH

One may ask this question why creating fuzzy set system for architecture variables which leads to Design solution. Fuzzy logic concepts are not direct support to decision making in architects creative work but it is an application in the area of development of research tools and method within the theory of architecture. The purpose of the study is to explore the field of mathematics or artificial intelligence (AI) for the analysis of architectural design, based on perceptions, experience, feelings and opinions that are purely qualitative or intangible aspects in nature. Fuzzy logic (FL) is a form of valued logic, it deals with reasoning that is 'Approximate' rather than 'Fixed' or 'Exact'. It is a way to transform non-intuitive and non-precise concepts to the measurable and accurate results. In the last decade algorithms are being developed which are particularly suitable for such non-analytical design problems. Such methods are collectively referred to as soft computing [5]. Although AI more than a decade is applied to Architecture by means of expert systems, the soft computing methods involving fuzzy logic is not commonly established in this discipline and therefore the associated technology is still not enough exploited in this discipline. However soft computing technology is essential for Architecture since it can deal with 'soft' data, which constitute the major source of architecture information. [6]

V. WHAT IS ARCHITECTURE DESIGN?

Architecture design is the science / art of shaping spaces it can be build and open. Buildings are constructed to fulfill need of safe, comfortable accommodation. To elaborate 'aspects' of building architecture in terms of comfort, function, safety and visual aesthetics are the main four parameters.

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Architects and designers work to fulfill the requirements with knowledge base, skill and experience. Perception about architecture/ Space may vary person to person as end user. The change of opinion / perception may cause due to various 'psycho-social' parameters which affects the individual's perception about comfort, function, safety and Visual aesthetics of architectural design. In the upcoming section of the paper we tried to elaborate various parameters or/ as variables of any one aspect of architecture as described above. Further, to build the studies consider 'comfort' as aspect of architecture. The fig-1 represents the various parameters or variables which affects the comfort of any space. In, general let establish a relation as described. As a parameter comfort is a combination of all attributes as variables. Attributes are variable in nature and need to collect data through questioner from expert / professional opinion to identify gravity and preferences of variables which contributes in achieving comfortable spaces.

VI. METHODOLOGY

The methodology of fuzzy assessment has developed to weight and evaluate **parameters (P_1 to P_7)** of architecture design, out of many as a case study demonstrating the single parameter 'comfort' and further to evaluate the total weightage for an optimum favorable condition for 'comfort', in fig.-2 comfort has elaborated into **attributes (C_1 to C_8).**

A. FUZZY LOGIC METHODOLOGY:

While defining a fuzzy model we need to consider following three main tasks [8], the fuzzy models presented in this paper were developed using only the first two tasks. :

i. Selection of an appropriate family of parameterized functions.
ii. Interviewing of human experts familiar with the target system to determine the parameters of the membership functions used in the rule base.
iii. Refining the parameters of the membership functions using regression and optimization techniques. .

The process of fuzzy logic is explained here, firstly, a crisp or classic set of input data are gathered and converted to a fuzzy set using linguistic variables, fuzzy linguistic terms and membership functions. This step is known as Fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the Defuzzification step. Defuzzification provides a transition from fuzzy set to a constant number. [9], [10].

B. DATA COLLECTION:

After defining the 07 Nos. of Building Architecture Design parameters as 'P_1, P_2,….,P_7' and restricted the study to demonstrate the method to only single parameter 'comfort' which is 'P_3'. Further to establish & build the research, comfort has been sub divided into 08 Nos. of attributes as 'C_1, C_2,….,C_8'. Now to quantify the comfort parameter, conducted a survey to take opinion from the professional architects as respondent (R) according to their experience and perception. Every respondent 'R' has been asked to give weightage to each attribute on 1 to 10 scale.

R_1, R_2, R_3, R_4,…….., R_{29}, R_{30} are the various respondents 'R_i' (i = 1 to 30) to questions.

certain set of

C_1 [Temperature], C_2 [Ventilation], C_3 [Furniture Layout], C_4 [Size or Volume], C_5 [Landscape], C_6 [Material Used], C_7 [Light Condition], C_8 [Visual Aesthetics] are the 08 attributes 'C_j' (j = 1 to 8) for weightage needs to give. (Table-1)

Weight 1 and 10 represent minimum and maximum weightage **'$W_{i.j}$'**.

C. DATA SYNTHESIS or DEFUZZYFICATION:

Let's assume, If ≥ 80% respondents gives weightage ≥8, ≥7, ≥6, ≥5 and ≥4 to any attributes (C_j) than it reveals that 90%, 80%, 70%, 60% and 50% respectively respondents are in support of the truthness or in favor of the attribute and the rest are in support of falseness of architectural parameter, then the membership value of fuzzy set will be: {0.96, 0.98, 0.65, 0.75, 0.55, 0.65, 0.80, 0.65}.

All independent expert's views for individual attribute will lead to a fuzzy set of the universe 'U':

U = {C_1, C_2, C_3, ……, C_8}

Let 'μ' be a fuzzy set of a finite set 'C'. Suppose that to each element c ∈ C, there is an associated weight $Wc_j \in R+$ (set of all non-negative real numbers).

Then the weighted rating of the fuzzy set 'μ' is the non-negative number $a(\mu)$ represented by: [11]

$$a(\mu) = \sum_{j=0}^{n} \{\mu(Cj).(Wcj)\}$$

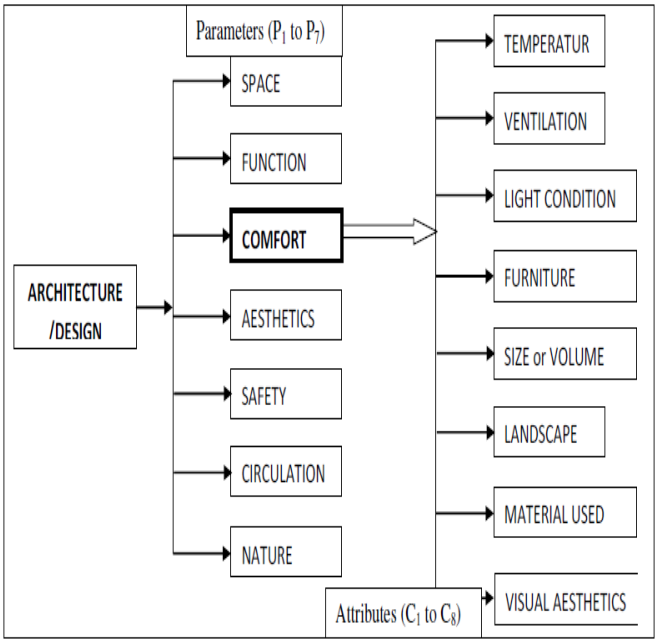

Fig. 2: Attributes of Architecture/ Design (Source: Author)

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Table-1: Various Criterions to evaluate Comfort as attribute:

Respondents (R_i)	Attributes 'C_j', j = 1 to 8 (weightage '$W_{i.j}$' of each attributes by individual expert)							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
R_1	$W_{1.1}$=8	$W_{1.2}$=9	$W_{1.3}$=6	5	5	4	6	$W_{1.8}$=5
R_2	$W_{2.1}$=9	9	7	7	6	6	8	6
R_3	$W_{3.1}$=8	8	8	8	7	6	7	6
R_4	$W_{4.1}$=7	8	6	6	5	5	7	7
R_5	8	7	6	7	6	6	8	8
R_6	9	8	7	8	5	6	9	6
R_7	10	9	7	7	6	7	8	7
R_8	8	8	6	7	6	5	7	6
R_9	9	9	6	6	5	6	7	6
R_{10}	9	9	7	7	6	6	8	7
R_{11}	10	10	7	7	6	6	8	7
R_{12}	9	9	6	7	6	6	8	6
R_{13}	8	8	7	8	6	7	9	6
R_{14}	9	9	7	6	5	5	7	7
R_{15}	7	7	6	7	5	5	7	6
R_{16}	8	8	6	8	5	5	7	6
R_{17}	8	8	6	7	5	6	8	6
R_{18}	9	9	6	7	6	6	8	5
R_{19}	8	9	6	7	6	6	9	6
R_{20}	8	8	5	8	6	5	8	6
R_{21}	8	9	6	8	5	6	8	6
R_{22}	10	10	7	8	6	6	9	7
R_{23}	9	9	6	8	5	7	8	7
R_{24}	9	9	7	9	6	6	8	7
R_{25}	8	9	6	8	5	6	9	6
R_{26}	9	8	7	9	5	7	8	8
R_{27}	9	9	7	9	6	6	8	7
R_{28}	10	10	6	9	5	7	9	$W_{28.8}$=7
R_{29}	9	9	5	8	5	6	8	$W_{29.8}$=6
R_{30}	8	9	6	7	6	$W_{30.6}$=7	$W_{30.7}$=9	$W_{30.8}$=6
Mean of Weights of each Attributes (X_j) $= \sum_{i=1}^{30} W_{i.j} / 30$	x1 $= \sum_{i=1}^{30} W_{i.1}$ = 8.6	x2 $= \sum_{i=1}^{30} W_{i.2}$ = 8.7	x3 $= \sum_{i=1}^{30} W_{i.3}$ = 6.3	x4 $= \sum_{i=1}^{30} W_{i.4}$ = 7.4	x5 $= \sum_{i=1}^{30} W_{i.5}$ = 5.5	x6 $= \sum_{i=1}^{30} W_{i.6}$ = 5.9	x7 $= \sum_{i=1}^{30} W_{i.7}$ = 7.9	x8 $= \sum_{i=1}^{30} W_{i.8}$ = 6.4
$\mu_A(C_j)$	$\mu_A(C_1)$ =0.96	$\mu_A(C_2)$ =0.98	$\mu_A(C_3)$ =0.65	$\mu_A(C_4)$ =0.75	$\mu_A(C_5)$ =0.55	$\mu_A(C_6)$ =0.65	$\mu_A(C_7)$ =0.80	$\mu_A(C_8)$ =0.65

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Table-2: The cumulative membership value of each attributes judged by different experts are given below

Comfort Attributes (C_j)	In support of Truthness $\{\mu_A(C_j)\}$	In support of Falseness $\{1 - \mu_A(C_j)\}$	Mean Weight of the attributes 'X_j' (Wc_j)	Weighted Rating = $[\{\mu_A(C_j)\} \times Wc_j]$
C_1	0.96	0.04	$Wc_1 = 8.6$	**8.26**
C_2	0.98	0.02	$Wc_2 = 8.7$	**8.53**
C_3	0.65	0.35	$Wc_3 = 6.3$	**4.10**
C_4	0.75	0.25	$Wc_4 = 7.4$	**5.55**
C_5	0.55	0.45	$Wc_5 = 5.5$	**3.03**
C_6	0.65	0.35	$Wc_6 = 5.9$	**3.84**
C_7	0.80	0.20	$Wc_7 = 7.9$	**6.32**
C_8	0.65	0.35	$Wc_8 = 6.4$	**4.16**
	Total Weighted Rating = $\sum[\{\mu_A(C_j)\} \times Wc_j] = \{a(\mu)\}$			**43.79**

Range of Fuzzy Assessment Results:

In order to achieve the optimum comfort condition. Following may be the 'Weighted Rating Range'; the assumed range may vary from one case to another:

Uncomfortable **if 0 < a (μ) ≤ 30**
Less Comfortable **if 20 < a (μ) ≤ 50**
Comfortable **if 40 < a (μ) ≤ 70**
Very Comfortable **if 60 < a (μ) ≤ 100**

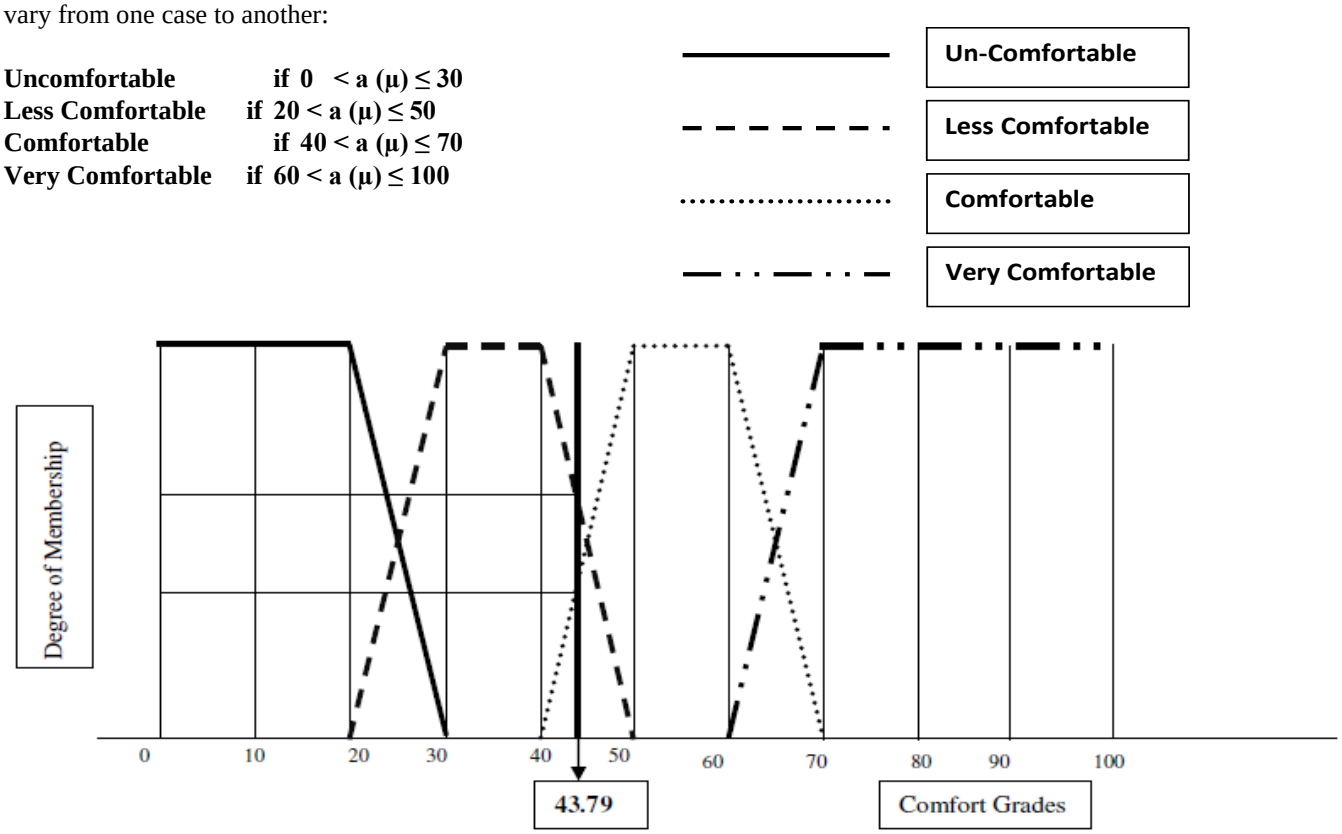

Fig. 3: Membership Function for the degree of Comfort

VII. CONCLUSION

The above methodology has shown how to evaluate the building architecture design parameters, by collecting qualitative or intangible data through expert opinion in terms of weightage. Unlike classical or crisp set where the value may be '0' for the support of falseness and '1' in support of truthness, in fuzzy logic concept, value (weightage) of any attribute gathered through expert opinion may have the value ranges from 0 to 1. It has been observed that expert generally hesitate to give opinion on any parameter because it involves perception or experience based answers which contributes certain degree of truthness and falseness while allotting the weightage in terms of points on some scale. The proposed fuzzy logic model reduces the uncertainty and transforms non-precise concepts to the measurable and accurate results. The method is also enabling us to evaluate other parameters of building architecture design to identify the optimum levels.

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Annexure – 1

Questioner for Respondent:

'Rate the various Attributes of *Architectural Comfort* on 1 to 10 scale as weightage.'

Questions asked to the various respondents (R) are as follows:

Q.- 1 How '**Temperature**' affects the 'Comfort' condition give the weightage.

1	2	3	4	5	6	7	8	9	10

Q.- 2 Rate the '**Ventilation**' in contributing comfort situation.

1	2	3	4	5	6	7	8	9	10

Q.- 3 Give weightage to '**Furniture Layout**' in achieving comfort condition.

1	2	3	4	5	6	7	8	9	10

Q.- 4 How 'Size or Volume' of space affects the comfort, rate it.

1	2	3	4	5	6	7	8	9	10

Q.- 5 '**Landscape**' adds comfort to space, rate the landscape.

1	2	3	4	5	6	7	8	9	10

Q.- 6 Rate the '**Materials**' used in the building.

1	2	3	4	5	6	7	8	9	10

Q.- 7 How '**Light Condition'** impact the comfort condition.

1	2	3	4	5	6	7	8	9	10

Q.- 8 '**Visual Aesthetics'** of architecture design contributes to improve comfort, rate it.

1	2	3	4	5	6	7	8	9	10

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