Journal of Informatics Education and Research
ISSN: 1526-4726
Vol 5 Issue 3 (2025)

"Optimizing Affordable Housing: A Quantitative And Qualitative Analysis Of Multidimensional Quality Parameters Using PCA"

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Abstract :
The problem of housing for low income individuals is one of the largest concerns of the world today, hence the need to find ways of making housing more equitable in terms of cost yet improve the quality. As such, this qualitative research evaluates PCA as a tool for improving the selected major quality parameters of affordable housing projects. As one of the active participants in dimensionality reduction, PCA offers recommendations with regard to the choice of sites, layout plans, the financial side of projects, and packages. Data collection and normalization and all the components influencing quality of housing are established using PCA. The results make a contribution to building the framework for decision making of how sustainable solutions in the building processes can be reached in a good quality and at present affordable way. Thus, this paper provides valuable lessons on the complex nature of affordable housing challenges, as well as signposts for enhancing project outcomes. Shelter is among the basic Human necessity that man cannot afford to do without, and affordable shelter is the order of the day considering the current world. The research in this study is concerned with establishing these relationships and the degree of variation in affordable housing projects through analyzing PCA on quality parameters. It also supports in decreasing the noise besides the critical factors such as site selection, layout design, business models as well as packages for construction. The study seeks to conduct a quantitative data collection and then clean the data before carrying out a PCA in order to find out the factors that influences the quality of housing.

Keywords: Initial Evaluation, Quantitative Outcome, Housing Delivery, Basic Characteristics, Built Environment

1. Introduction:

Housing still costs a lot, and a lot of the people, especially in the developing world market, are still not easy to get affordable and good quality housing solutions. Growth of population densities places an enormous strain on government, developers and planners to devise ways to deal with these density increases, while at the same time assuring that housing continues to be affordable. With cities being added in their expansion, increased demand for residential spaces does, and to a need to identify cost effective yet quality driven housing development solutions is of importance. Building affordable housing projects involves many stages and the success of these projects is affected by a combination of external and internal factors. The selection of a site for the project that incorporates the existing ecosystem, the resulting layout, the financial sources that influence the overall feasibility of the project and the method of construction that

affects cost, time, and quality, etc., are among the factors that can be elaborated. Each of these factors not only dictates the affordability of the housing projects but also decides their sustainability. The urban population growth makes the technological progress and depletion of resources more apparent. This is because the denser population not only creates an urgent need for more effective planning, resource distribution, and construction management but also demonstrates the requirement for efficient methods through the higher demand. It is imperative to manage these factors with powerful analytical tools capable of spotting the inefficiencies and making the process more efficient. Data-driven methods such as principal component analysis (PCA) are extremely helpful in tackling issues related to the production of affordable housing. PCA is a very efficient statistical method that has found application in almost every field, particularly in data mining and pattern recognition. It has always been meant for feature reduction in a dataset but keeping only the most important features as per the outcome. In the case of using PCA, the housing project's participants can break down the large data sets into the few parts that contribute the most to quality and affordability of housing. PCA also helps in identifying the areas that will need more attention in terms of the allocation of resources, selection of sites, selection of construction materials, and strategies for funding, especially in the case of affordable housing. To help focus stakeholders' attention on the aspects of housing quality that can have the greatest impact on cost while maintaining effectiveness, the key determinants of housing quality have been isolated. This approach is of great merit since it helps policymakers, urban planners, and construction firms effectively distinguish basic housing necessities from other attributes that contribute to improved living standard [1].
This analytical framework can illustrate the interrelation between cost and quality in affordable housing projects and facilitate better decisions which may not just be the provision of minimum-level housing but also the raising of overall quality of life. This is especially significant considering recent researches that have rather forcefully suggested the adoption of alternative research practices in the housing development field, as such practices enhance not only planning effectiveness but also producing sustainability in the often-disputed urban growth areas. Indeed, [2,13] use PCA to demonstrate its strength in urban planning as a mighty technique for obtaining key insights from high-dimensional and complex data through successful mining. By its ability to separate these major factors from housing project decision variables, PCA assists in allowing planners to focus on the most influential variables in avoiding redundant or overlapping contributions to project decisions, thus reducing the amount of time that is used for decision making. [3] also stressed the importance of using data to make decisions in the management of housing project resources. It revealed the benefits of using data analytics in improving resource allocation efficiency which increases project housing outcomes. In affordable housing, effective resource management is even more crucial because there are many constraints in terms of the financial as well as the materiality parameters one has to balance between cost reduction and quality gain. With cities growing, we are to see increasing use of data analytics and hence PCA and other such statistical tools becoming even more indispensable in formulating the future housing policies.

Affordable housing development application of PCA offers structured structure to optimize the project design, planning and execution, and it provides a scientific basis for relaunching strategies and improving tactic to support the management of short term and long term housing

needs. Based on an existing research, this study aims to extend research on affordable housing using PCA and study how PCA can best be used to improve project quality and delivery. This research has importance, however, insofar as it can offer an analytical framework that takes into consideration the special problems associated with projects working for clients who—in most cases—have their own special socio-economic conditions and floating needs. And in the rise of growth of housing projects, there is a growing change of urbanized environments.

When building or implementing socially and environmentally sustainable housing initiatives, the importance of integrating both the socioeconomic and environmental factors, has been stressed by the Division of Housing. Referring to the note of [4], sustainable housing plans should be adopted in context of various factors such as energy consumption, environmental impact, choice of construction material for construction, and long term sustainability of the infrastructure. With PCA, policy makers can get actionable insights that are financially sustainable while meeting sustainability goals. The most important facet of urban planning deals with the intersection of analytics in data and the sustainable housing strategies. as a transforming method of dealing with one of the most significant problems in urban planning, it is the integration of PCA into housing development. This study proposes through the lens of key indicators, and optimal implementation of the resource management, and proper strategic decision making to bridge the gap between affordability and quality in housing projects. Given the continuing growth of cities and increasing housing needs, housing policies and urban development will increasingly rely on data driven methods.

2. Literature Review

Affordability is one of the major issues in housing that require a very high input quality for the quality of the sustainability while the liveability of the dwellers. Indeed, PCA is considered one of the most important tasks in the case of a large number of data and makes use of the available tools to define the housing with a high quality roles. PCA's ability to work on large data sets and to get to the bottom of the affected variables about affordability, sustainability and also housing quality means that it is an important method for building housing policies and construction methodology. It is because of this that **Liu et al. [6**] explained the application of PCA in the explaining process of the urban planning, being such a crucial tool in reducing the number of dimensions in a data set while being more structured support of the decision making processes in housing organizations. This enables an urban planner to extract the most important factors inducing unaffordability and sustainability, which, in turn, facilitates rational deployment of resource and project implementation strategy. According to **Abdi and Williams et al. [5]**, PCA is primarily helpful when the number of data is big and the manufacturing of dwelling features of value addition. PC leaning facial recognition is a relatively simple algorithm and often comes with several subjective criticisms, such as their reliance on linear relationships, or the inability to kinect non linear trends in data; however it has a list of advantages which supersede it's disadvantages when applied to affordable housing analysis. PCA is used in the present discussion for assessing affordable housing projects in developing criteria of evaluation, ranking of data, and solution for improving housing interventions. **Jolliffe and Cadima et al., [1]** define as critical in the efficacy of housing policy to select the most impacting variables to guide the men and woman of the policy and development to intervene in what will generate the greatest changes in affordability and sevatability.

Iwata et al. [10] performed PCA analysis in order to reveal key housing quality attributes that are related to major affordability and sustainability aspects. In the lack of cash and materials, affordability projects are seen as high risk and discouraging the many developers. This reluctance points to the need for such tools to help reduce the risk in investments in affordable housing. In their work, **Mulliner Maliene et al. [12]** looked at critical success factors in affordable housing projects and listed such parameters for project success as site selection, design efficiency, and financial management. These match with the study presented by **Gan et al. [8]** that investigated the sustainable housing solutions and how the technologies of advanced construction can improve housing quality without losing cost competitiveness. Hence, modern construction methods like modular housing and prefabrication can be applied to low-cost housing projects to establish a novel area of co-existence between the two opposites of affordability and sustainability. The price of housing is a central issue in the debate. Chen et al. [6] noted that socio-economic factors significantly impact people's housing costs, and in this respect, they determine what housing types different social strata can afford to live in. The above situation underlines the need for housing policy-making that will take into account the varied requirements of the population so that no low-income and marginalized communities will be left out of the housing projects.

Wang et al. [11] further argued that environmental conservation strategies should be incorporated in the affordable housing projects. The argument made by the authors is that green building practices including energy efficient designs and use of sustainable materials will help to achieve greater reduction in housing development environmental footprints and enhance long term affordability. Furthermore it adds weight to support the arguments for compounded housing development, an approach in which literacy, affordability, sustainability, and the participation of the community are considered together. For the success of compounded development with housing, there is need of active community participation to tailor housing solutions for the residents specifically, as noted by **Dovey and King et al. [7]**.

They also have observed that for housing projects have been unable to locate analytical tools and data driven methods. **Zhang et al. [14]** propose using modern analytical tools as PCA in order to determine how many resources should be spent in a combination to net the most while still keeping costs affordable. Results from the literature conclude that PCA is important in enhancing quality parameters of low cost housing projects by simplefying complex data and pointing out major factors determining the success of the project. PCA helps increase understandability of differences in large data sets, and thereby strengthen housing development decision making. An optimized affordable housing solution needs to be balanced in terms of financial feasibility with its sustainability objectives from a socioeconomic, environmental, and policy viewpoint. Simplicity and Sustainability is an inclusion adding in housing development to make the solutions match the diverse needs of different population groups throughout the whole process also at the same time economically viable. Therefore, this research has great relevance for stakeholders associated with sustainable urban development and affordable housing.

3. Experimental Method

3.1 Taguchi Method

In this study, efficiency of the Taguchi method in the optimization of these quality parameters of affordable housing projects is realized. This method consists of a systematic and organized technique of determining the important variables affecting multi factorial processes in order to enhance performance characteristics as well as minimizing the variability [15]. Key control factors, including the building design, budgeting, site selection and construction methodologies, are studied to a fine degree in order to apply the Taguchi method to affordable housing developments. At different levels, these factors are examined for the best fit between quality and cost. Part of the Taguchi method is the orthogonal array design that allows us to evaluate multiple factors at the same time without the need of doing exhaustive experimentation [16]. Such a design means that each of the factors' influence upon housing quality is covered comprehensively and the most influential variables may be identified. In the first step of experimental process, an objective needs to be clearly defined, a set of control factors need to be selected, and the levels of these control factors need to be chosen. To have an overall vision of all the involved factors, a balanced experimental runs are conducted by using an orthogonal array. One of the main features of the Taguchi method is the determination of signal to noise (S/N) ratio that measures a quality characteristic in terms of the inherent variability. The use of methodical calculation of S/N ratio helps discovery of the best settings that combined better quality and lower cost. Later, the same results are further refined using Analysis of Variance (ANOVA) under the Taguchi framework to determine statistically significant contributing factors. The Taguchi method is applied in this study as a tool for designing a complete optimization model for affordable housing parameters. The research not only attempts to improve housing project quality but also seeks to achieve the long term sustainability of housing projects via integration of Taguchi principles. The applications of this framework in the future can change affordable housing by making high quality and affordable solutions available to different populace and thus promote sustainable development of the urban.

3.2 PCA of Experiments

Since Principal Component Analysis (PCA) is a well used statistical tool, it can be employed for this research, and among other advantages, enables translational of the established variables, and in general facilitates the reduction of dimensionality necessary to disclose which parameters have most impact on affordable housing variability. In implementing PCA with large datasets, the obtained new variables known as principal components are independent of each other, which helps to simplify complex data. The components are linear combinations of the original variables, which maximize variance in the dataset, but are as redundant as possible. By using this method, unnecessary information is removed and less important variables so that only relevant information remains, which is a powerful instrument for housing quality analysis.
There are actually several critical steps that are involved in performing PCA. The first step to take involves normalizing and standardizing the data to make sure that all variables contribute equally to the analysis and the result wouldn’t matter what unit or scale. The next step is to calculate the covariance matrix of the data to establish the relationship between variables. Finally, the third and last step is to computes the eigenvalues and eigenvectors of the covariance matrix [17]. The eigenvalues indicate the proportion of the variance that is kept in each

principal component which is determined; the eigenvectors show the direction of maximum variance in the data. PCA is not only helpful in discovering the most influential parameters in affecting affordable housing, it also facilitates the decisions by giving clear understanding on the structure of the underlying data. This makes it possible for researchers to concentrate on more critical factors, such as cost, quality and sustainability in accessing the use of the system in projects of affordable housing.

RUN	Site Selection	Layout Plan	Finance	Packages	Appraisal
1	31	400	50	2500	63
2	31	750	90	2550	45
3	31	1000	95	2650	54
4	40	400	90	2650	72
5	40	750	95	2500	88
6	40	1000	50	2550	98
7	49	400	95	2550	65
8	49	750	50	2650	73
9	49	1000	90	2500	73

Table 1:- Experimental Values for PCA

For a given data matrix X:

- **Standardize the data:**

$$\mathbf{Xstd} = \frac{X-\mu}{\sigma}$$

Here, is the original data matrix or X given in section 4. is the average of each feature (column) in the dataset, is standard deviation of the each feature.

The result, is the normalized data where every variable is brought to a mean of 0 and a standard deviation of 1. This step also makes it easy to perform the analysis by making sure that all the features are given equal importance.

- Compute the covariance matrix:

$$\mathbf{C} = \frac{1}{n-1}\ \mathbf{Xstd}^{T}\ \mathbf{Xstd}$$

$Xstd^{\top}$ is the transpose of the standardized data matrix.

The covariance matrix C describes the pairwise covariances between the different features (variables) of the dataset. This matrix captures how the variables in the dataset vary together (whether positively or negatively correlated).

- Solve the eigenvalue equation

$$\mathbf{Cv}=\lambda\mathbf{v}$$

C is the covariance matrix, vvv represents the eigenvectors, and λ\lambdaλ represents the eigenvalues. Solving this equation gives us the eigenvalues and the corresponding eigenvectors). The principal components are the directions in the dataset that account for the most variance, and the corresponding eigenvalues tell you how much variance is explained by each principal component.
Include eigenvectors with the highest eigenvalues among all the eigenvectors computed, taken into account any number . The transformation into the principal component space is given by: =(std Z=Xstd) where is the matrix of selected eigenvectors.
By evaluating affordable housing projects of PCA further, one identifies areas of great concern, makes conclusions as to the influences that create more impact and in the process pinpoints the right practices needed in improving on affordable housing **Shlens et al. [17].**

Table 2:- Table of Outputs Parameters

RUN	Satisfaction	Scope Of Redevelopment	Appraisal	Commute
1	78	90	63	95
2	75	85	45	82
3	82	94	54	78
4	75	52	72	65
5	88	82	88	80
6	80	63	98	53
7	90	72	65	80
8	70	78	73	57
9	95	75	73	70

4. Result:-

A primary concern related to the Principal Component Analysis (PCA) data analyzed under the Taguchi method was the performance metrics of the MPCI_NF1 and SN_MPCI_PCA_NF1 parameters. The MPCI_NF1 values varied significantly from 6375.999 (the lowest) to 8264.957 (the highest), which reflects both a great deal of variation and also a chance to improve performance metrics. The factors that have an impact on the housing project's efficiency can thus be adjusted in a systematic way to get the best overall results.

In contrast, the SN_MPCI_PCA_NF1 has a considerably narrower spectrum of values ranging from 1275.200-1652.991 which signifies more dependable performance. Such reliability is very much needed for the purpose of telling apart the parameters that bring about the highest project output. The research demonstrates the Taguchi technique's might in parameter optimization, therefore stressing its role in the design of low-cost housing. It can be inferred from the results that the relationships between the parameters discovered can be very closely scrutinized resulting in significant advances in both performance and cost, thus the quality and sustainability of low-cost housing projects will be improved. It is recommended that further research be conducted in the future to explore these interrelations in depth and to validate the optimization strategies that were proposed through this analysis.

MPCI_NF1	SN_MPCI_PCA_NF1

8264.957	1652.991
7384.073	1476.815
7445.702	1489.140
6720.796	1344.159
7173.197	1434.639
7027.833	1405.567
6954.383	1390.877
6375.999	1275.200
7007.207	1401.441

Table 3:- Table of Process Capability and Principal Component Analysis Metrics

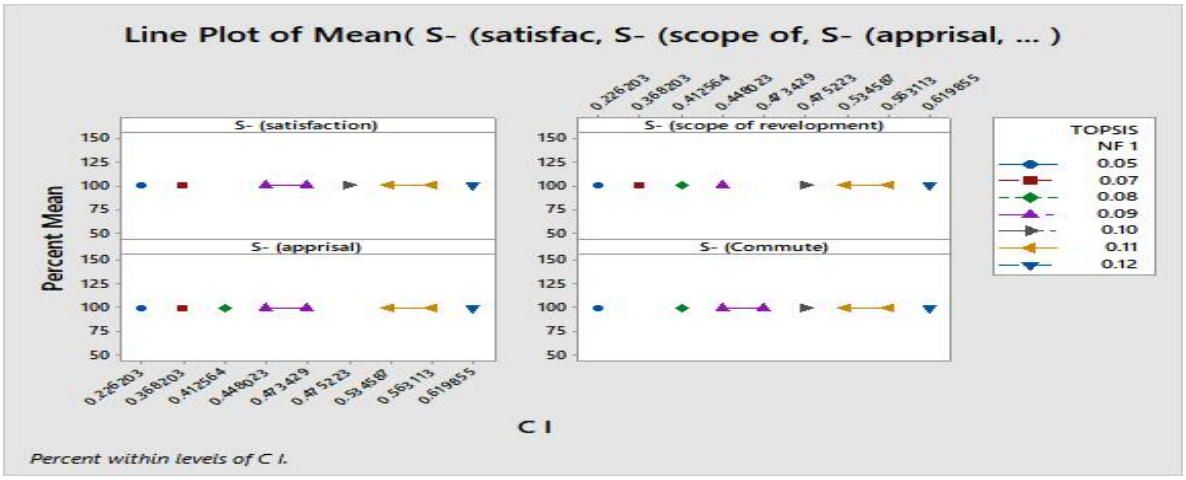

Figure1:- Line Plot of parameters of Consistency Index

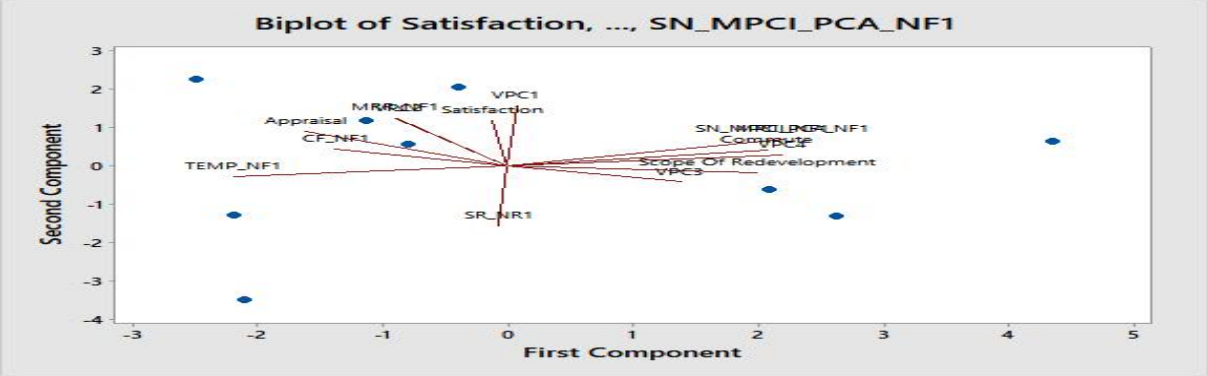

Figure 2:- Biplot for the PCA

5. Conclusion

This research has made it clear that the Taguchi method's use for optimizing parameters in low-cost housing projects is indeed worth it as a major source of quality and performance improvement. The results showed an astonishing variation in the values of the MPCI_NF1 from 6375.999 to 8264.957, so there was an opportunity to change the variables that were most effective in contributing to the overall efficiency of housing projects. On the other hand, the values pointed to a smaller interval of 1275.200 to 1652.991 indicating similar performance more or less equally across the evaluated parameters.

The paper puts forth the blending of Taguchi method and PCA as a single unified approach that keeps both the design and the realization of money-saving housing projects together. The versatility of housing solutions made possible through Taguchi method's parameter optimization under different conditions gets palatable and usable in various locations. This adaptability is very important since the issue of housing development that can be solved by the adoption and application of this method is an issue already regarded as the most serious one in terms of economic, environmental, and social aspects. At the same time, the method brought out in the study offers the leaders, policymakers, and developers a way to mix the information-based approaches that will not only raise the quality of the occupants but also keep the costs profitable. Despite the fact that, very importantly, the study still points out the need for optimization techniques for sustainable housing solutions so they can achieve not only cost and quality improvements. The research brings together the Taguchi method and PCA to set the pace for a continuous improvement in the design to affordable housing road map. The findings of the investigation validate the call for permanently incorporating into practice the previously mentioned optimization proposals as the means of delivering housing quality with a reduced environmental footprint. The urban population growth rates in developing areas will be the main reason for the continuous need to enhance these methods to meet the housing demand of low- and middle-income groups. The testing of the proposed strategies should be included in the future work, along with the exploration of other factors that affect the performance of this kind of housing. Among these factors is the influence of external factors on the design, such as climate conditions, energy efficiency standards, and the evolution of urban policy. The combined use of life cycle assessments (LCA) and real-world case studies would not only strengthen the applicability of the proposed optimization strategies but also ease the appropriate real-world transfer of results into actual housing solutions. Furthermore, since Taguchi and PCA methods are still in their infancy, it could be a good approach to enhance their performance by combining with AI and ML the methods for houses optimization.

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