Analysis, evaluation and optimization of house layout by response surfaces

Daniel das Neves Martins

Departamento de Engenharia Civil, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brasil. e-mail: martinsddn@uem.br

ABSTRACT. The project and development of a product represents an area of great interest and importance for producers and consumers. A project transmits an identity which may be called a solution to the product and, in this context, it presents a vast range of possibilities, revealing its strategic importance. The challenge for house draftsman is to adjust the pertinent variables to a solution for optimization of the product. A loss model and construction of response surfaces of relevant variables is presented to aid towards the geometric solution of the project. The method allows the analysis, evaluation and optimization of the project solution.

Key words: optimization of the project's solution; quality, loss model, response surface.

RESUMO. Análise, avaliação e otimização de arranjos físicos de habitações, através de superfícies de resposta. O projeto e desenvolvimento de um produto representam uma área de grande interesse e importância para produtores e consumidores. O projeto transmite uma identidade que pode ser uma solução ao produto, e apresenta uma vasta gama de possibilidades, que revelam uma importância estratégica. O desafio para o projetista de habitações é ajustar as variáveis pertinentes em uma solução que otimize o produto. É apresentado um modelo de perda e construção de superfícies de resposta de variáveis relevantes, com o intuito de auxiliar na solução geométrica do projeto. O método permite a análise, a avaliação e a otimização da solução de projeto.

Palavras-chave: otimização da solução de projeto. qualidade, modelo de perdas, superfície de resposta.

Introduction

Quality may be evaluated according to the approach discussed by Taguchi and Clausing (1990) with reference to intrinsic losses and harmful collateral effects caused by the product to the community. Losses are basically caused by the variability of the product's intrinsic function (losses caused by the product's variability during its life span) and by harmful collateral effects of the product (associated to its use). Its basic premise is to achieve the product's quality from its project, or rather, the projecting of a sufficiently robust product to guarantee quality in spite of the variations that may occur during the production process and its employment. The key factor of the premise is the reduction in the variations of the product's performance with regard to its target values.

Archer (1971) states that target values indicate the direction towards which changes are due, or rather, for something better and for optimization. Demirkan *et al*. (1992) remark that they are attributes that the projectionist wants to have them revealed at the project's final stage. Chan (1992) and Arge (1995) consider them crucial in the project's development and influencing factors of its quality.

Taguchi analyzes the need for fixing a target value for quality and emphasizes that undesirable costs occur when the aim is not reached. This is due to the fact that quality loss is equal to zero; for a fixed target it is an increasing value due to target distancing. This premise is defended, among others, by Ballard and Koskela (1998), for whom loss reduction is the chief principle for the optimization of the project's solution. Likewise, from the client's point of view, it is the method for obtaining the best solution for a project.

The analysis of spatial configuration of a house seen from the quality approach, endeavored by Taguchi, establishes the delimitation of different quality levels according to the greatness of qualifying variables in the physical arrangement. The contrast between these values and the target value, which represents the quality desired, determines that the lack of such variables within the context of the adopted target, is a loss of product utilization (for example, confinement of environments, walls without possibility of placing furniture against them, insufficient space in the utilization of the environment and a great number of halls).

Thus, a model for the determination of a loss index with regard to the development and the optimization of the housing's physical arrangement is here suggested.

Strategic focus of the architectonic design

The starting point of an architectonic composition is reproduced by inner space which is obtained from space units made from their delimitating walls, floor and ceiling, as traditional elements, and doors and windows as connections with the interior and the exterior environment (Krier, 1988). They fix the technical elements of space. They are thus understandable and describable, while defining size, proportion and form. Components refer directly to the environmental function and to the layout composition which must take into account the habitation of people, the accommodation of furniture and the execution of certain domestic activities.

Problems on the layout of a habitation design comprised many satisfactory solutions. At present, they represent one of the greatest hits in research since they seek methodologies for the development of multiple options and mainly of algorithms for the optimization of solutions.

Characterized by a multiplicity of options and by an effort to optimize solutions, the strategic idea is particularly indicated in the development of products in the design phase. At the same time various solution options should be taken into account and evaluated so that the design of an optimized product could be attained (Nutt, 1988).

Investigations and developments in the solution for an architectonic design by a great number of possibilities start from the development of formal process models of the architectonic design by computer, artificial intelligence and cognitive psychology (Akin *et al*., 1992; Akin and Sen, 1996). They produce a multiplicity of layouts, which indicate solution strategies.

The chief difficulty in the development of layouts of spaces by the mathematical model is associated with the topological and geometrical solution (Woodbury, 1991; Jo and Gero, 1995). In their turn, they raise two important problems: the generation of arrangements and the optimization of solutions.

The generation of layouts delimits a problem that has been already researched by more than a dozen developed systems (Akin *et al*., 1992).

The problem of choosing a solution or its optimization is much more complex. According to Liggett (1980), no algorithms developed with this aim in view are extant. This is also Steve's position (1996) who insists that one of the consequences is the forced and arbitrary halt of search which reduces the number of options and diminishes the hope of finding the optimization of a solution. It is one of the themes developed in the present research work.

The development of an algorithm that would verify the optimization degree of a solution of an apartment's layout relating geometric quality with geometric variables may be used, besides making possible the optimization of solutions, as an indicator of the quality of the product, as a type of information of entrepreneurs' strategy in decision making (Oliveira *et al*., 1993; Oliveira, 1996), as a monitoring of results by firms and by market (Langford and Male, 1991).

Finally, the algorithm may be a decisive factor in the analysis of a solution with regard to the layout of an architectonic design and a quality policy. Together with other evaluation methods, it may be a contribution towards habitation improvements.

Quality evaluation of apartment projects

There are at present different methodologies, especially in Europe, to evaluate the quality of an apartment's architectonic design. SEL and Qualitel methods are worth mentioning. The two methods have been considered cases of multicriteria analysis (Bezelga, 1984) by which apartment valorization is processed for its utility function. According to Brandon (1984), the set of delimitating factors of the utility function contributes towards a certain degree of satisfaction and defines the value of the building. Although it is a concept developed in economical theory, in the case of a building it is extremely difficult to quantify especially by money terms. A solution for this difficulty (Brandon, 1984) leads to the establishment of different possibilities of designs, with various quality levels, with more imaginative solutions, a development strategy and new options by the producer. It will enhance quality options that the consumer market desires or hopes to reach by means of the apartment it would like to acquire.

Evaluation of the geometric quality of apartments' space configuration

Methodology (Martins, 1999) employed for the analysis and evaluation of geometric and nominal quality of apartments' layout and applied to a sample built from layouts of one hundred apartments, type three bedrooms, projected and commercialized in Brazil as from 1995, will be shown in the following sequence:

Establishment of geometric variables in layout, according to procedures:

1. graph representation of projects in CAD and limitation of geometric and quantifying variables of the layout;
2. determination of geometric variables and qualifying attributes of apartments' layout;

3. list of values of geometric and qualifying variables of layout of projects.

The adoption of a physical arrangement representative of the desired quality (called target project *AA*) is a must, required by the model's demands. Relative values of evaluated physical arrangements are comparatively calculated. Demands are also due to the requirements of compatibility of the mathematical model of the sum of indexes of the horizontal and vertical planes.

According to Gitlow (1993), desired quality is the clients' and consumers' feeling and appreciation with regard to degrees by which a product attends to or exceeds needs or expectations. Full expectations are represented (value equal to 1.0 in a scale from 0 to 1).

Qualifying index of internal configuration and exteriorization, employing equations (01) to (03):

$$IKI = \frac{CK}{2.(AU)^{1/2}} \quad (01)$$

$$CK = CO + CA - CN \quad (02)$$

$$IKE = IEX = \frac{CE}{2.(AU)^{1/2}} \quad (03)$$

Index of geometric quality with equations (04) to(12):

$$IE = \frac{ke}{m}\frac{AU}{(AU)^{1/2}} \quad (04)$$

with: *m* = meter, and

$$ke = \left(AU^{-1/6}.AA^{1/6}\right) \quad (05)$$

$$IEaa = \frac{(AA)^{1/2}}{m} \quad (06)$$

$$CQ = CE + CK \quad (07)$$

$$IKC = IKE + IKI = \frac{CQ}{2.(AU)^{1/2}} \quad (08)$$

$$IKCaa = IKEaa + IKIaa = \frac{CQaa}{2.(AA)^{1/2}} \quad (09)$$

$$IKA = IE + IKC \quad (10)$$

$$IKAaa = IEaa + IKCaa \quad (11)$$

$$IQG = \frac{IKA}{IKAaa} \quad (12)$$

Calculation of nominal area of layouts by equation (13):

As from the geometrical quality index of physical arrangement, expressed by equation (12), the cost of the geometrical quality index is calculated according to the desired quality of the target project whose value is fixed by area. The cost thus obtained by equation (13) is the value by area of the project analyzed after the losses in desired quality within the target project have been calculated. AN value less than the value of serviceable area means losses in the target condition (desired quality). When the AN value is higher than AU there is a quality level higher than that used by the target project.

$$AN = AA.(IQG)^3 + \varepsilon \quad (13)$$

Index of nominal quality of layouts.

The proportional relationship between the serviceable and the nominal areas is called the nominal quality index, suggested by equation (14). The nominal quality index is the loss index. In physical terms, IQN amounts to the fact that in a flat with a serviceable area (AU) of 100.0 m^2 and with a nominal area (AN) of 90.0 m^2, the dweller acquires 100 area units. However, when the desired quality is taken into account, the flat has a loss of 10.0 m^2, which determines a nominal quality index of 0.90. It also represents the possibility of optimization of the project's solution through the flat's physical arrangement of 90.0 m^2 and a nil loss index.

$$IQN = \frac{AN}{AU} \quad (14)$$

Legend of variables:

AA = serviceable area of target design, in m²;
AN = nominal area of layout, in m²;
AU = serviceable area of layout, in m²;
CA = broadened perimeter, in meters;
CE = external perimeter, in m;
CK = internal qualifying perimeter, in m;
CN = non-furnishable perimeter, in meters:
CO = sum of the physical arrangement's internal perimeters, in meters;
CQ = total qualifying perimeter, in m²;

IE = spaciousness index of layout;
IEaa = spaciousness index of target design;
IEX = exteriorization index;
IKA = qualifying index of layout;
IKAaa = qualifying index of layout of target design;
IKC = qualifying index of configuration;
IKCaa= qualifying index of the configuration of target design;
IKE = qualifying index of external configuration;
IKEaa= qualifying index of external configuration of target design;
IKI = qualifying index of internal configuration;
IKIaa = qualifying index of index configuration of target design;
IQG = index of geometric quality of space configuration;
IQN = index of nominal quality of space configuration;
m = metric factor;
ε = randomized error.

Value map of an apartment's layout

Attributes of an apartment's layout are chiefly geometrical in nature. At the horizontal plane, they consist of floor and ceiling, and at the vertical one, delimiting walls and divisions together with connecting elements; they are represented by doors and windows. The designer defines different options of solutions from these attributes. On evaluation the designer suggests that which better conforms to the specifications of the problem. Solution may be obtained by quantification of quality and by the delimitation of loss, associated with the product's quality. He will thus combine the alternatives in a value map that will contain the design's geometric composition, the visualization of the solution's parameters and, consequently, the choice of the best alternative (Malen, 1996). According to Kapur and Cho (1996), a region of multiple characteristics of quality and of choice options may be determined and outlined.

A systematization of solutions, which would help the designer in the evaluation of the design's best solution, or rather, the optimization of the apartment's layout, is established by response surface of the response variables, nominal quality index. This is representative of the geometrical quality of space configuration with regard to geometric variables, which define and qualify the design's solution.

Value map of nominal quality index

According to methodology suggested, analysis, evaluation and optimization of layout of an apartment are processed by the nominal quality index IQN.

The construction of a map of values of response variable IQN as a function of the chief geometric variables which determine the habitation's layout (serviceable area AU; length of walls: total length PT, external length CE, contour perimeters CC), and the number of rooms of the layout NC, leads to the graphic evaluation of the geometric quality of space configuration.

Graphs forming value maps were prepared from a data bank of two hundred three-room flats (Figure 1).

Analysis of map of values of nominal quality index

Analysis of surface response is processed by response variable, nominal quality index IQN, with regard to geometric variables AU, PT, CE, CC and NC. The goal of this analysis is to verify the behavior of variables when related to response variable, the determination of a maximization region. The displacement of variables towards this region of maximum response is enhanced so that solution may be optimized.

Response surfaces reproduce some of the behavior possibilities of dependent variable, quality index of geometric solution (response), with regard to independent geometric variables (observed). The latter define the design's geometric composition and determine the qualifying attributes of the geometric solution of an apartment's space configuration.

The establishment of a data bank with layouts of similar habitations in terms of geometric variables and qualifying attributes, valid within a certain context (regional, cultural, technological and typological, among others), allows the construction of response surfaces and the determination of nominal algorithm of the design. Analysis, evaluation and optimization of designs of a habitation with same characteristics are thus rendered possible.

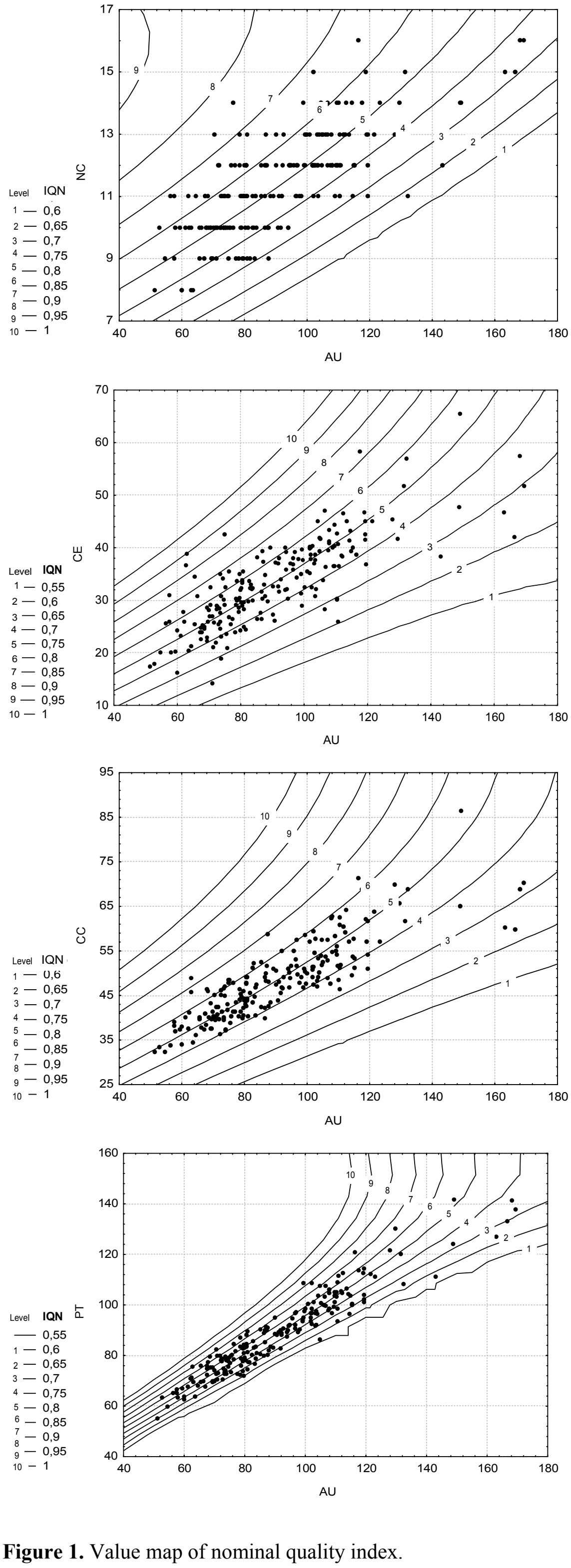

Figure 1. Value map of nominal quality index.

Legend:
AU = serviceable area of layout, in m²;
PT = quantity of total walls, in meters;
CC = perimeter of the layout, in meters;
CE = quantity of external walls, in meters;
NC = number of rooms of the layout.

Conclusion

Many other attributes which have not been analyzed in the model should undoubtedly be integrated within a more widened evaluation of integral quality of such a complex product as housing. Most are, however, extremely difficult to quantify.

The methodology for the establishment of a quality index of a geometric solution of an apartment's space configuration and the response surfaces define a system of analysis, evaluation and geometric optimization of a design. Aims associated to the model and chiefly to the nominal quality index and to the design's nominal algorithm are defined by the following:

1. Computerized optimization of layouts of habitations;
2. Quality indicator of geometric solution of a design's or a product's (habitation) layout;
3. Indexation and classification system of apartments;
4. Information for entrepreneur strategy in decision taking, monitoring of results of internal and external environment (market and competition);
5. Optimization of the project's solution from the client's point of view.

In the preliminary phase, the nominal algorithm of design and map of values are far-reaching tools for the designer. In this phase the definition of space configuration of an apartment or the evaluation of a design forwards analysis of alternatives towards geometric solutions evaluated by response variables as a function of the geometric variables that determine layout and qualify the solution. It also delineates an advance in the area of habitation designs for a better comprehension of the mechanisms of the composition and the optimization of space configuration of apartments.

The model suggesting a loss index for housing product in our study showed, by means of a series of simulations, that values determined by the model converge with physical reality. This means that a low nominal quality index value is equivalent to geometrical conditionings that determine losses in the utilization of the housing product (confinement of environments, walls without any possibility of any furniture against them, extensive hall length, non-optimized environmental sizes and others).

When the quality approach, seen from the loss angle, is utilized as a point of departure for the calculation of the quality index of the project's solution, it is possible that, through the establishment of quality variables of a determined product, to build a loss model similar to that developed in the current case study. This will surely optimize the project's solution and cause the optimization of the product to the benefit of the client and of society.

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