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APPLYING THE CONCEPT OF TOTAL BUILDING PERFORMANCE TO ASSESS THE QUALITY OF BUILDINGS

BY

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Abstract. Total Building Performance (TBP) addresses a set of coordinated strategies aimed at assessing the quality of a building, in terms of the extent to which all the requirements of performance are satisfied, namely: spatiality, structural integrity, fire resistance, safety in operation, energy performance, air quality, thermal comfort, acoustical and visual comfort. It examines and develops processes contributing to the delivery of integrated and high performance buildings with respect to needs and resource availability. The paper aims to ilustrate the application of quality function to evaluate the overall performance of buildings and the steps to be taken. As an application, the calculation scheme presented was used to evaluate the overall performance of a residential building to be rehabilitated. Building quality assessment based on overall performance indicator is a means of comparing the various options for choosing the best. System performance evaluation based on the concept of merit is to integrate all the requirements and performance criteria formulated by specialists, the subjective indicators reflecting the level of user satisfaction, and can be applied both for separate buildings and urban ensembles.

Key words: total building performance; building assessment; performance; comfort.

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1. The Concept of Total Building Performance

The concept of overall performance, Total Building Performance (TBP), emerged in the last decades of XXth century, provides a tool for assessing the quality of a building, in terms of the extent to which all the requirements of performance are satisfied, namely: spatiality, structural integrity, fire resistance, safety in operation, energy performance, air quality, thermal comfort, acoustical and visual comfort (Cotana & Goretti, 2007; Roulet, 2004).

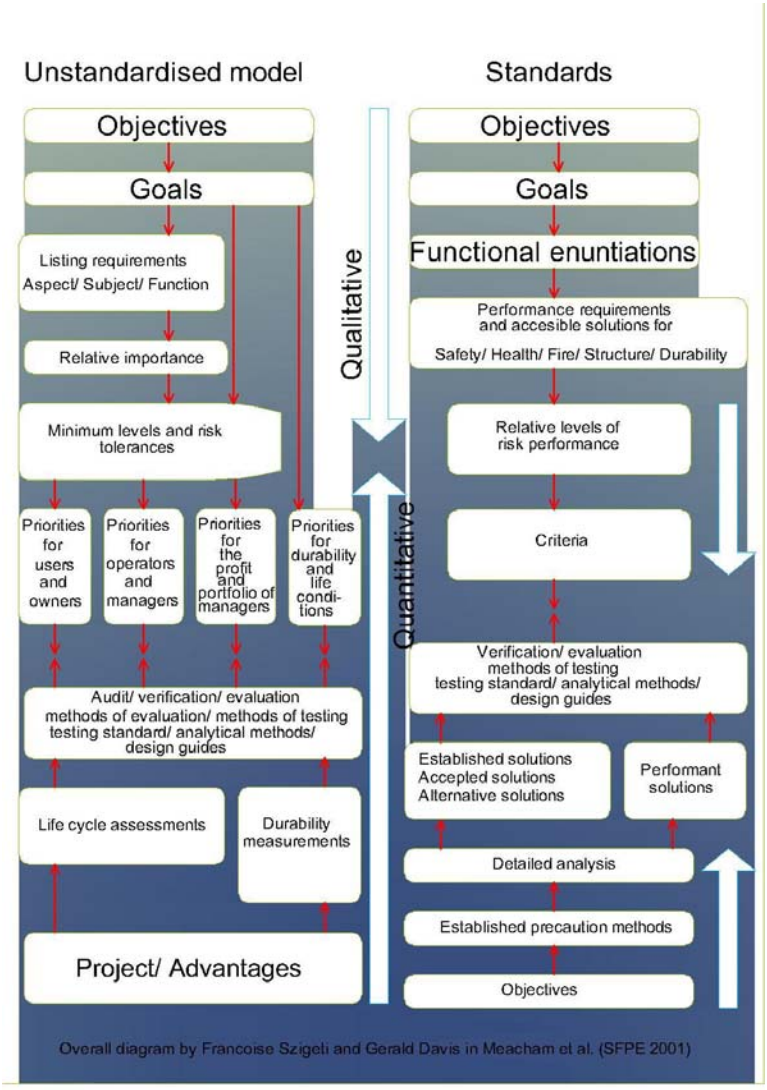

Fig. 1 – General evaluation scheme using the concept of total performance.

The field has been the subject of numerous studies in terms of performance mandates and integration into the building system by defining the requirements of physiological, psychological, sociological and economic levels (prEN 15251, 2006). The general scheme of steps to be taken in applying the concept of overall performance is shown in Fig.1.

2. Overall Performance Assessment Model with the Applying of Quality Function

2.1. Theoretical Outlines

Quality Function Deployment (QFD) is defined as a technique to transform user demands into design requirements and their formulation at the level of subsystems, components, parts, materials or production processes. Application of quality function in the complex evaluation of the building product assets – design, implementation, utilization – can be find in the works of Dong-Eun Lee and David Arditi who's matrices are presented in Figs. 2 and 3, taken from *House of Quality* (2006).

		HOW_1	HOW_2	HOW_3	...	HOW_n
		IH_1	IH_2	IH_3	...	IH_n
$WHAT_1$	IW_1	I_{11}	I_{12}	I_{13}	...	I_{1n}
$WHAT_2$	IW_2	I_{21}	I_{22}	I_{23}	...	I_{2n}
$WHAT_3$	IW_3	I_{31}	I_{32}	I_{33}	...	I_{3n}
					...	
$WHAT_m$	IW_m	I_{m1}	I_{m2}	I_{m3}	...	I_{mn}

Fig. 2 – Original data matrix.

			HOW_1	HOW_2	HOW_3	...	HOW_n	Level of Performance (LP_i)
			H_1	H_2	H_3	...	H_n	
			PH_1	PH_2	PH_3	...	PH_n	
$WHAT_1$	W_1	PW_1	R_{11}	R_{12}	R_{13}	...	R_{1n}	LP_1
$WHAT_2$	W_2	PW_2	R_{21}	R_{22}	R_{23}	...	R_{2n}	LP_2
$WHAT_3$	W_3	IW_3	R_{31}	R_{32}	R_{33}	...	R_{3n}	LP_3
						...		
$WHAT_m$	W_m	IW_m	I_{m1}	I_{m2}	I_{m3}	...	I_{mn}	LP_m
Level of Performance (LP_i)			LP_1	LP_2	LP_3	...	LP_n	LP

Fig. 3 – Matrix of data processing.

Notation used in matrixes shown in Figs. 2 and 3 have the following meanings: WHAT – customer exigencies; IW_i – importance weight of each

option based on user requirements; HOW_i – performance criteria; IH_j – importance share of technical characteristics established by experts assessing product quality; I_{ij} – the relation between WHAT and HOW determined by independent evaluators; W_i – normalized importance weight for WHAT; H_j – normalized importance weight for HOW; R_{ij} – score using eq. (1); PW_i – users expected level of meeting the requirements; PH_j – expected level of meeting the requirement evaluated by experts; LP_i – level of performance obtained on the basis of eq. (4);
LP_j – level of performance obtained on the basis of eq. (5); LP_i – level of overall performance.

Quality assessment of a building based on quality function involves going through five steps namely

1. Identification of requirements and data collection (Fig. 2). The original data matrix contains information (IW_i) on user requirements (WHAT), technical characteristics of the product (IH_j) and the connection between them (I_{ij}).

2. Processing of the data in the matrix of data processing (Fig. 3). The matrix in Fig. 3 has a further row indicating the expected level of meeting the requirement evaluated by experts (PH_j) and a column designating the expected level of meeting the requirement of users (PW_i). These levels are placed on a scale from 1 to 5, between satisfactory and excellent. R_{ij} score for each intersection between WHAT and HOW is calculated with eq.

$$R_{ij} = \frac{W_i \times \mathrm{PW}_i + H_j \times \mathrm{PH}_j}{2} I_{ij}. \tag{1}$$

Share the importance of the data matrix is normalized on the basis of relation

$$\sum W_i = 0, \tag{2}$$

$$\sum H_j = 0. \tag{3}$$

3. Calculation of the maximum level of performance that can be achieved. The maximum level of performance (max LP) is reached when all the WHAT and HOW criteria are fully satisfied, namely are rated with 5 (excellent).

Maximum values for LP_i , LP_j and LP are calculated with relations

$$\max\ \mathrm{LP}_i = \sum R_{ij},\ \ i \ldots m, \tag{4}$$

$$\max\ \mathrm{LP}_j = \sum R_{ij},\ \ j \ldots m, \tag{5}$$

$$\max\ \mathrm{LP}_j = \sum \max\ \mathrm{LP}_i = \sum \max\ \mathrm{LP}_j. \tag{6}$$

4. Calculation of the actual level of performance. Obviously, the actual level of performance will be determined by effective levels of WHAT and HOW ranging in values between 1 and 5. The calculation is identical to that of the step 3.

5. Quality performance indicator calculation (QPI). Overall quality indicator is determined with relation

$$\mathrm{QPI} = \frac{\mathrm{LP}_{\mathrm{ef}}}{\mathrm{LP}_{\mathrm{max}}} \cdot 100, \quad [\%]. \tag{7}$$

2.2. Model for Assessing the Overall Performance of Buildings Based on Quality Function

The application of quality function to evaluate the overall performance of buildings is shown in Fig. 4. Completed data must be entered and the steps are as follows:

a) *Column 1* includes quality factors of the building representing user requirements formulated in qualitative terms, namely that is intended from the building. The share of their importance is determined by users expressing an option by filling out questionnaires rating on a scale of 1 to 10, where 1 represents “not important” and 10 “very important”. Normalized values of the weightings are placed in an adjacent column.

b) *Line 2* includes performance criteria (or performance factors) of the building that can be quantitatively assessed by calculation or measurement. They define the expectations of users from the building products. The relative importance of these indicators can be assessed by evaluation experts or users, based on questionnaires.

c) *Matrix 3* represents the degree of importance of the relation that exists between user requirements and performance criteria. Information is provided by users on a rating scale from 0 to 5, zero being "no connection" and 5 “perfect connection”.

d) *Column 4* represents the quality factor of achieving perfect conditions, the level of satisfaction being rated 5 for all user requirements.

e) *Line 5* contains the values of the normalized importance weights concerning performance criteria.

f) *Line 6* is associated with levels of performance criteria in perfect condition, when all criteria are met at level 5.

g) *Matrix 7* contains scores calculated on the basis of a), c), d), e) and f) points according to eq. (1).

h) *Cell 8* represents the maximum level of quality that can be associated with the building in perfect conditions and operating performance calculated with the procedure defined by eqs. (4),...,(6).

i) *Column 1* is the actual level of satisfaction of user requirements assessed on the basis of processing results of the questionnaires.

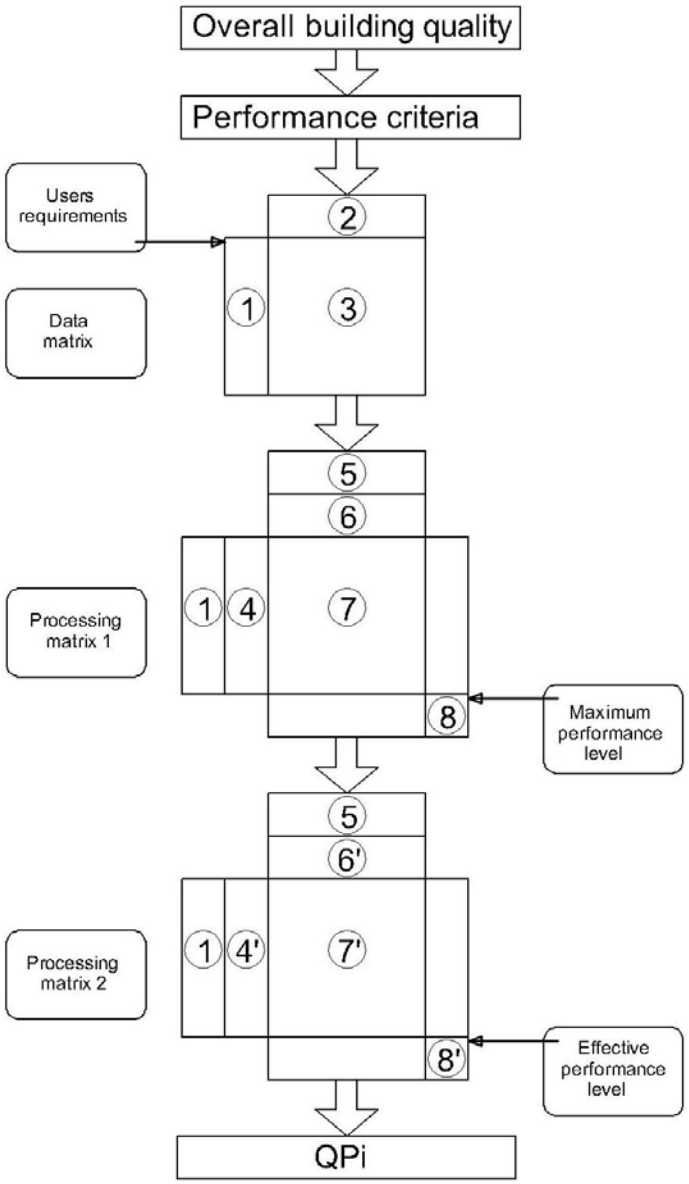

Fig. 4 – Model assessment of buildings (rehabilitation project) based on quality function.

j) *Line 6* is the actual level of achieving the performance criteria as evaluated by specialists.

k) *Matrix 7*' contains scores calculated on the basis of a), c), d), e) and f) points on the basis of eq. (1).

l) *Cell 8* represents the actual level of performance determined for specific conditions and operating performance, according to eqs. (4),...,(6).

2.3. Example for the Application of Quality Function to Evaluate the Overall Performance of a Building

As an application, the calculation scheme presented in § **2.2** was used to evaluate the overall performance of a residential building to be rehabilitated. User requirements that come directly related to the rehabilitation process and performance criteria that determine the quality of the building were taken into account.

The list of these requirements of WHAT expected from the building after rehabilitation, is as follows:

$WHAT_1$ – Space and functionality.

$WHAT_2$ – Structural integrity and operational safety.

$WHAT_3$ – Energy performance.

$WHAT_4$ – Comfort.

$WHAT_5$ – Investment expenses.

Performance criteria, which show HOW user requirements are the followings:

HOW_1 – Thermal comfort.

HOW_2 – Acoustic comfort.

HOW_3 – Visual comfort.

HOW_4 – Indoor air quality.

			HOW_1	HOW_2	HOW_3	HOW_4	Performance level (LP_i)
			0.325	0.207	0.228	0.240	
			5	5	5	5	
$WHAT_1$	0.220	5	2.78	2.668	3.360	3.45	1.198
$WHAT_2$	0.247	5	0	0	0	0	0
$WHAT_3$	0.154	5	5.987	0.902	3.342	2.955	13.186
$WHAT_4$	0.236	5	7.012	5.537	5.80	3.57	21.919
$WHAT_5$	0.143	5	5.625	0.875	2.782	2.872	12.15
Peformance level (LP_j)			21.344	9.983	15.284	12.847	**59.457**

Fig. 5 – Maximum performance assessment matrix.

A number of elements required by the assessment procedure, such as the weight of the importance of various requirements and performance criteria, were adopted from the literature or proposed by the evaluators based on the experience and relationships with users (Lee & Arditi, 2006). Effective performance levels were assessed by calculation based on data contained in the

rehabilitation project. It was assessed the maximum possible level of performance that the building can reach (Fig. 5) and the actual level (Fig. 6).

Overall performance of the building is

$$QPI = \frac{LP_{ef}}{LP_{max}} \cdot 100 = 76.80. \quad (8)$$

			HOW_1	HOW_2	HOW_3	HOW_4	Performance level (LP_i)
			0.325	0.207	0.228	0.240	
			4	3	5	3	
$WHAT_1$	0.220	4	2.18	1.876	3.03	2.40	12.198
$WHAT_2$	0.247	5	0	0	0	0	0
$WHAT_3$	0.154	4	4.79	0.618	3.073	2.04	10.485
$WHAT_4$	0.236	4	5.61	3.912	5.21	2.496	17.228
$WHAT_5$	0.145	3	3.89	0.525	2.353	1.723	8.49
Performance level (LP_i)			16.47	6.931	13.66	8.659	**45.705**

Fig. 6 – Matrix assessment of the actual performance.

3. Conclusions Regarding the Possibilities of Evaluating the Quality of the Building through the Concept of Total Performance

Building quality assessment based on overall performance indicator is a means of comparing the various options for choosing the optimal. A correct application necessarily involves knowing user requirements and conversion to performance requirements (Kian, 2001; Fazzio *et al.*, 2002). The process is laborious, requiring extensive investigative work based on questionnaires and statistical processing of data obtained. A similar manner must be applied to establish the weights of importance. It is true that once carried out a database in this respect, for a certain type of building, it can still be used to evaluate the performance of any project or rehabilitation of a building with the same destination. Actual levels of performance can be assessed on an objective, calculations or measurements, based on the assessment of users / customers or combined (Directive 2002/91/EC). Development of a general framework for evaluation in this respect to use validated computer software is absolutely necessary. System performance evaluation based on the concept of merit is to integrate all the requirements and performance criteria formulated by specialists

the subjective indicators reflecting the level of user satisfaction, and can be applied both for separate buildings and urban ensembles.

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APLICAREA CONCEPTULUI DE PERFORMANȚĂ TOTALĂ (TBP) LA EVALUAREA CALITĂȚII CLĂDIRILOR

(Rezumat)

Conceptul de performanță totală – Total Building Performance (TBP) – apărut în ultimile decenii ale secolului trecut, oferă un instrument de evaluare a calității unei clădiri, din punct de vedere a măsurii în care sunt satisfăcute totalitatea exigențelor de performanță, respectiv: spațialitate, integritate structurală, rezistență la foc, siguranță în exploatare, performanță energetică, calitatea aerului, confort termic, confort acustic şi vizual. Acest articol îşi propune să ilustreze aplicarea funcției calitate pentru a evalua performanța totală a clădirilor şi paşii care trebuie parcurşi. Ca o aplicație, schema de calcul prezentată a fost folosită pentru a evalua performanța totală a unei clădiri rezidențiale care trebuie reabilitată. Sistemul de evaluare, bazat pe conceptul de performanță totală, are meritul de a integra exigențele şi criteriile de performanță formulate de specialişti cu indicatori subiectivi care reflectă nivelul de satisfacție a utilizatorului, pretându-se a fi aplicat atât la clădiri considerate separat, cât şi la ansambluri urbane.