A MODEL APPRAISING THE PERFORMANCE OF STRUCTURAL SYSTEMS USED IN SPORTS HALL AND SWIMMING POOL BUILDINGS IN GREECE

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ABSTRACT. The selection of the best performing structural system (among steel, timber laminated, concrete, fabric tents) for medium span (30-50m) sports halls and swimming pools in Greece formed the impetus for this research. Decision-making concerning selection of the structural system is difficult in this sector of construction, as was explained in the "Long Span Structures" conference (November 1990, Athens, Greece). From the literature it has been found that most building appraisals end up at the level of data analysis and draw conclusions on the individual aspects they investigate. These approaches usually focus on a fraction of the problem, examining it very deeply and theoretically. Their drawback is loss of comprehensiveness and ability to draw conclusions on an overall level and consequently being applicable to the existing conditions. Research on an inclusive level is sparse. In this particular research project, an inclusive appraisal approach was adopted, leading to the identification of three main variables: resources, human-user-satisfaction, and technical. Consequently, this led to a combination of purely quantitative and qualitative data. Case studies were conducted on existing buildings in order to assess the actual performance of the various alternative structural systems. This paper presents the procedure followed for the identification of the research variables and the focus on the development of the model of quantification. The latter is of vital importance if the problem of incompatibility of data is to be solved, overall relation of findings is to be achieved and holistic conclusions are to be drawn.

1. Appraising Building Performance

The problem of decision-making during building design, in terms of structural materials, subassemblies and constructional systems used, is an old one (CIB 1975) and, as Preiser (1988) argues, still has not been solved. This decision-making problem is closely related to the evaluation of the building elements in order to identify their properties and subsequently their applicability for certain needs. The same problem exists as far as evaluation in use is concerned; according to Shibley (1982) "Buildings need constant adjustments to the needs of their users", leading to a continuous need for assessment evaluation and fine tuning of the building objectives, following users' feedback-feedforward, to use Markus' (1972a, 1972b) terminology.

Building performance has been investigated and researched a lot in the past - especially during the 1960s and 1970s. W60 (1975), commissioned by the CIB on the performance concept, stated that: "As a term to characterize the fact that products must have certain properties to enable them to function when exposed to stresses the word performance has been chosen." The notions and approaches of the last 15 years can be identified through Preiser's (1988) definition: "In the performance concept, the behaviours, qualities and accomplishments of people and things are measured and evaluated."

The aims of the performance-related studies can be classified in three main categories. The first is the performance concept itself, in terms of identifying problems, investigating and setting performance requirements, criteria and performance specifications for particular building types. The second is evaluation of buildings in the design stage, employing the performance concept as

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a tool for the analysis and evaluation of proposed solutions. And finally, the third is the appraisal of buildings in use, evaluating existing buildings.

The evaluations of buildings are of two types: the partial, dealing with particular aspects of building performance; and the inclusive, incorporating all aspects of performance in a structured and systematic way. The partial ones may be cost-dependent, analyzing the economic factors and considerations; quality-dependent; or cost-time-dependent. The last is a relatively new trend due to implementation of more advanced economics and the changes in the financing methods followed.

There is great confusion as far as the terms evaluation and appraisal are concerned. It is widely believed that they both imply a process by which various solutions to a particular problem are tested and selected - that is prior to the actual implementation. Furthermore, evaluation is closely related to some sort of scores or values. According to Bishop (1978), "Appraisal is the process by which completed buildings are assessed, judged or evaluated by the client, the users (if distinct from the client), the designers or by a combination of any of these." Another name given to appraisals during the late 1970s, is post-occupancy evaluations (POE). Preiser (1988) points out that the philosophical and theoretical foundation of POE is the performance concept: "POE is an appraisal of the degree to which a designed setting satisfies and supports explicit and implicit human needs and values of those for whom a building is designed." In their more rigorous forms, POEs follow a systematic approach where all user groups are represented and all important design elements are examined. The concept of appraisal, as analyzed by the Building Performance Research Unit (BPRU, Markus 1972a, 1972b), is related to the establishment of the quality or performance of a solution and incorporates three basic steps: "Representation in which the solution is modelled in a suitable way. This representation may be verbal, mathematical, visual or even full-scale (a building in-use is a full model). Measurement where the performance of the model is obtained on as wide a variety of counts as necessary. Finally evaluation, when the measured results are processed."

The literature survey showed that the approaches followed in the evaluation of buildings can be broadly classified in two categories: theoretical and practical. Theoretical partial approaches examine rigorously a narrow section of the whole building performance issue, leaving many aspects and variables untouched. On the contrary, inclusive approaches being systematic analyze all aspects and present a holistic view. However, they tend to be "all breadth and no depth" (Bishop 1978) and unless used with great care do not produce significant results (SSBRT 1976). The majority of theoretical approaches are of the framework type, identifying some variables and measuring each one individually (partial). They consequently fail to develop an overall measure of building performance or a model for the quantification of the results.

On the other hand, the criteria set and the models developed in practical approaches are suitable for specific building types only. As these are mostly conducted by public sector departments, the criteria are mainly related to the use, function and maintenance costs. These are more technically oriented than the highly theoretical inclusive approaches. Only a few theoretical approaches, the so-called model appraisals, reviewed in the literature develop a model, BPRU being one of the better established and widely known. This model is inclusive, focusing on school buildings, although the team that developed this model argue that it can be modified and applied in various building types. The important characteristic of this approach is that the building is divided in four sub-systems (building, environmental, activity-behaviour and organizational) and related to each sub-system is a measure of cost. Consequently, all four sub-systems are interrelated and examined in total, enabling the drawing of inclusive conclusions.

Another model is that for the assessment of expected performance effectiveness developed by Crise (1975). This model focuses on industrialized buildings and examines them in terms of technological and economic performance capabilities. It is not an inclusive model since sociological, psychological and environmental issues are not considered; the two points that make it worth noting are its application and model. It is applied in the pre-selection stage, assessing various alternatives. An explicit classification of techno-economical variables is presented in three levels. Following the calculation of the relative effectiveness indices for the two first levels, the overall effectiveness index of each industrialized building is calculated.

2. The Problem

The already-mentioned global problem of evaluating and assessing the appropriateness, effectiveness and in general the performance of the various structural systems and materials used in buildings is equally applicable in Greece, though it is more apparent in long spanning structures. In buildings spanning up to 15 metres, in-situ reinforced concrete is the dominant structural material being produced locally. It is widely accepted by the engineers, labour force and public. In long spanning structures, over 25 metres, the situation is confusing. There are various opinions and arguments from architects, building engineers, contractors and theoreticians leading to a long-lasting debate. The importance of the debate, together with an increasing need for these structural types (exhibition, conference and sports halls, warehouses and swimming pools), forced the Technical Chamber of Greece to organize a Scientific Seminar on Long Span Structures (Athens, 1990). The main problems highlighted were the availability and suitability of structural materials, the need for new building standards, import of know-how on a permanent basis, quality control and educational needs of the engineers.

Considering the existing needs, future trends, number of buildings built, availability of data and variety of structural systems implemented, this research focuses on sports halls and swimming pools spanning 30 to 60 metres. Among the structural systems used are steel frames, ranging from space framed beams or 3D trusses up to space frames, all the forms of fabric and pneumatic structures, tents, inflated balloons, etc. and Glu-lam. Even reinforced concrete has been used, though rarely. Korbas (interview, 1990), architect and member of the Design Department of the General Sport's Secretariat (DDGSS), pointed out that the vast majority of these buildings are General Sport Secretariat (GSS) developments. As far as availability of information is concerned, the existence of this public board is critical.

The aim of the research is to find out which is the best performing structural system for sports halls and swimming pools in Greece. The methodological objectives set were to develop a model appraising the performance of sports halls and swimming pools in Greece and, following the analysis of a representative sample, to investigate and evaluate any impact of the structural system on the performance of sports halls and swimming pools in Greece. This paper is concerned with the initial analysis only, leading to the identification of the main variables. Additionally the problems related to the development of a model of quantification are presented.

3. Procedure of Analysis

The research method used is selected according to the type of research and information needed (Yin 1989). Following a classification of the sports hall and swimming pool buildings, an in-use evaluation of 15 buildings was conducted. This method combined some of the advantages of case studies (depth of the research) and surveys (variety - all building types examined), helping reach reliable conclusions as well as being more flexible. A model was constructed aiming at an overall measurement of building performance and facilitating the comparison between buildings of different structural systems. Building performance, according to SSBRT (1976) framework, is assessed in five systems: environmental, activities, technical, cost-resources, cultural-symbolic. Subsequently the effects of structural system changes on the environment, the activities, the resources and culture were examined, evaluated and correlated to produce an overall measure of building performance. The consequences of a change in the SSBRT's (1976) "technical system" (or according to Markus (1972a, 1972b) "building system") upon the building performance were investigated.

Analyzing the GSS briefs and particularly the Design and Build ones, the GSS model became more explicit. This model is based on the evaluation of proposals submitted by the contracting firms and incorporates two main variables: cost and quality. The first includes the building costs and overall cost of the building (excluding running costs), the costs of penalties for exceeding the construction deadlines set, and finally the overall construction period. Quality incorporates eleven parameters: aesthetics (external and internal appearance of the building), function (of the building in general, in relation to sports and to its surrounding environment), loadbearing structure (overall arrangement, selection, combination of the loadbearing members of the building and durability), lighting of the main hall, heating, plant room, machinery and e/m equipment, building materials, energy conservation systems, acoustics of the main hall and finally repairs and maintenance (selection of materials and constructional methods facilitating simplicity, flexibility and economy in repairing and maintaining the building). The relative importance of these parameters is not the same; analyzing this GSS model, their exact weighting was established, which is presented later in this paper.

4. Identification of the Variables

The model of appraisal developed for this particular research is based on the GSS model. The research focuses on aspects-issues influencing the performance of sports halls and swimming pools in Greece and at the same time affected by the selection of structural system. Consequently, few of the parameters listed were discarded as irrelevant to the research aims and objectives. The remaining parameters were analyzed from the different viewpoint of the research model and classified under three main variables: resources, human-user satisfaction and technical aspects. Resources, the first variable and the more clearly defined, is similar to the resources modifier of Hillier and Leaman (1972) and the SSBRT's (1976) cost-resources heading. This variable incorporates the cost and time variables of the GSS model. These are not only examined at the provision-construction level (as in construction costs and time spent of the GSS approach), but in-use (HVAC costs, energy conservation and maintenance) as well.

The second main dependent variable to be examined is the human-user satisfaction, including the physical environment, one of the two issues discussed in Markus' (1972a, p.10) environmental system: "aspects of the environmental system directly perceived as heat, light, sound, texture and smell" and psychological aspects. This second aspect that this variable deals with is presented in Zunde's (1982) analysis under the delight, visual aesthetics section and Preiser's (1988) behavioural elements of post-occupancy evaluation. Essentially, physical environment concerns heating, lighting and acoustics, whereas psychological aspects refer to the GSS aesthetics as well as the spatial configuration - similar to the functional parameter of the GSS model. The last main variable of the research is technical, similar to Preiser's (1988) category, where structural integrity, durability and general performance of the various building systems is assessed. This technical variable is identical to the SSBRT (1976) technical category and very close to the BPRU (1972) building system. However, only two out of BPRU's three sub-systems are examined: construction and services. The technical variable is divided in two: building structure and repair and maintenance. Building structure is assessed in terms of the two GSS model parameters of building materials and loadbearing structure, whereas repair and maintenance is reviewed as in the GSS analysis. The following table presents the three main variables, the aspects considered in each, and the relevant GSS parameters.

TABLE 1. Main research variables

Main variables	Aspects considered	GSS parameters
Resources	Cost Time	Cost Heating Repair and maintenance Time Energy conservation
Human-user satisfaction	Psychological aspects Physical environment	Function Aesthetics Heating Lighting Acoustics Machinery and equipment
Technical variables	Building structure Repair and maintenance	Building materials Loadbearing structure Repair and maintenance

Having structured the main research variables, the next step is to identify the independent and dependent ones, justify the selection and present the functions measuring them. As far as resources are concerned, two provision-construction cost indicators are considered in this particular research: the envelope and the services. The former includes sub-structure, superstructure and cladding. The latter incorporates heating, ventilating, air-conditioning and fire protection costs. In order to enhance comparability between various buildings with varying sizes, the floor area of the building is considered as well.

$$\text{Envelope} = \frac{\text{Substructure}+\text{Superstructure}+\text{Cladding}}{\text{Usable Floor Area}}, \quad \left(\frac{\text{drx}}{\text{m}^2}\right) \quad (1)$$

$$\text{Services} = \frac{\text{HVAC}+\text{Fireprotection}}{\text{Usable Floor Area}}, \quad \left(\frac{\text{drx}}{\text{m}^2}\right) \quad (2)$$

The only provision-construction time indicator the research examines is the rate of construction.

$$\text{Construction Rate} = \frac{\text{Usable Floor Area}}{\text{Actual Construction Period}}, \quad \left(\frac{\text{m}^2}{\text{days}}\right) \quad (3)$$

The in-use cost indicators that the research considers are running costs, regular maintenance and failure repair. Running costs include fuel, electricity and the wages of the permanent staff. The other two categories incorporate the labour cost involved as well as the cost of the necessary spare parts and materials.

$$\text{Running Cost} = \frac{\text{Fuel}+\text{Electricity}+\text{Wages}}{\text{Usable Floor Area}}, \quad \left(\frac{\text{drx}}{\text{m}^2}\right) \quad (4)$$

$$\text{Regular Maintenance} = \frac{\text{Labour}+\text{Materials}}{\text{Usable Floor Area}}, \quad \left(\frac{\text{drx}}{\text{m}^2}\right) \quad (5)$$

$$\text{Failure Repair} = \frac{\text{Labour} + \text{Spaces}}{\text{Usable Floor Area}}, \quad (\frac{\text{drx}}{\text{m}^2}) \tag{6}$$

Two of these are the in-use time indicators that this research considers: the regular maintenance and the failure repair.

$$\text{Regul.Mainten.Disruption} = \frac{\text{Days Lost Maintaining}}{\text{Usable Floor Area}}, \quad (\frac{\text{days}}{\text{m}^2}) \tag{7}$$

$$\text{Failure Repair Disruption} = \frac{\text{Days Lost Repairing}}{\text{Usable Floor Area}}, \quad (\frac{\text{days}}{\text{m}^2}) \tag{8}$$

It should be pointed out again that the in-use indicators are calculated annually. The following table draws the conclusion on the basis of previous analysis.

TABLE 2. Resources indicators

	Cost	Time
Provision	Envelope Services	Construction rate
In-use	Running Regular maintenance Failure repair	Regular maintenance Failure repair

Human-user satisfaction is a qualitative and highly subjective variable assessed through psychological and physical environment indicators. These indicators are classified in five main categories: aesthetics, HVAC, lighting, acoustics and functionality. As Markus (1972a, 1972b) explains, "as a consequence of the importance of the interaction of people and buildings, any examination of building performance should also take into account the quality of that interaction and the way in which the building influences it". Furthermore in order to proceed with the specific measurement of the above-mentioned interaction, it is necessary to collect empirical information about what people actually do and say in regard to their environment. Therefore, the qualitative parameters of the environment-activity interaction are measured through the subjective users' opinions. On the other hand physical environment indicators are assessed by the researchers, through objective or subjective measurements. Thus, in each category, psychological and physical indicators are related and compared in order to evaluate and assess the validity of the users' opinions and to enhance the capacity to draw conclusions.Aesthetics are further analyzed in appeal of the building as a whole and appeal of the hall alone. The relevant physical indicators are the shape and size of elevations, colours used for the first and main hall's properties in general and colours used for the second, recorded following personal observation of the buildings by the researchers.

In terms of HVAC, users' opinions are monitored. Additionally, the following physical indicators are considered: temperature considerations (proximity to the sea, open space or protected by buildings, strong winds, etc.), air quality (dust, pollution) and condensation. Users are also questioned on lighting issues, focusing on daylight intensity and glare problems. The relevant physical indicators are the window surface, texture and orientation, the properties (colour, texture, etc.) of the hall's walls and the number of hours that the artificial lighting is on during a day (time of day the lights are turned on during a certain month of the year).

Acoustics in general and the noise penetration from the surrounding environment are also considered. The physical indicators of the environment investigated by the researchers are traffic load, factories and other noise sources that are potential causes of disturbances. In terms of functionality, users are questioned on the safety and visibility of the buildings. The researchers are carrying out an observation of the whole building in order to identify areas of potential

TABLE 3. Human-user satisfaction indicators

	Psychological	Physical
Aesthetics	Appeal of the building Appeal of the main hall	Shape and size of elevations Colours used
HVAC	Heating Air quality-comfort Ventilation	Temperature considerations Air quality Condensation
Lighting	Natural light Glare	Window surface, texture and orientation Main hall's wall properties Usage of artificial lighting
Acoustics	Noise level in the hall Echo, clarity of sound	Proximity to noise sources
Function	Safety Visibility from seating	Wall's protrusions, smoothness Potential problem areas

problems such as the wall's protrusions and smoothness, etc. Technical aspects form the third main research variable. Repair and maintenance resources have already been discussed in previous sections, leaving aspects related to the building structure and maintenance to be presented and analyzed. Several indicators were identified: industrialization of structure, origin of structural materials, complexity of structure and maintainability. It was decided to develop cost-related functions for the measurement of these technical issues, as they offer the best indicators of the size of the relevant assemblies and are easily comparable.

$$\text{Industrialization} = \frac{\text{Prefabricated Members Cost}}{\text{Envelope Cost}}, \quad (\%) \qquad (9)$$

$$\text{Origin} = \frac{\text{Native Members Cost}}{\text{Envelope Cost}}, \quad (\%) \qquad (10)$$

$$\text{Complexity} = \frac{\text{Structural System Cost}}{\text{Envelope Cost}}, \quad (\%) \qquad (11)$$

$$\text{Maintainability} \left\{ \begin{array}{l} \text{Maintenance Staff Capabilities Needed} \\ \text{Spares Availability} \end{array} \right. \qquad (12)$$

5. Model of Quantification

Following the presentation and analysis of the three main variables, their relative importance must be established to enable an accurate evaluation of the performance of each structural system examined. The starting point for the development of a model of quantification was the GSS model and the relative importance of its parameters.

TABLE 4. Technical indicators

Industrialization	Extent of prefabrication
Origin of materials	Percentage of native materials
Complexity	Number and cost of sub-assemblies
Maintainability	Maintenance of staff capabilities Availability of spares

The next step was structuring the GSS parameters according to the main research variables and calculating their relative importance. As indicated previously, resources represented costs, time, part of repair and maintenance, energy conservation and part of heating. The percentages derived are therefore $42 + 4.2 + 3 + 1.9 + 1.6 = 52.7$. Similarly, human-user satisfaction represents

TABLE 5. GSS parameter grading

Parameter	%
Cost	42.0
Time	4.2
Aesthetics	8.4
Function	11.2
Loadbearing structure	8.4
Lighting	2.5
Heating	3.6
Plant room	2.3
Machinery, e/m equipment	5.3
Building materials	3.4
Energy conservation	1.9
Acoustics	2.3
Repair and maintenance	4.5

aesthetics, function (only part of the whole), lighting, the rest of heating, machinery and equipment (part only) and acoustics, which leads to $8.4 + 5 + 2.5 + 2 + 3 + 2.3 = 23.2$. Finally, technical indicators are related to loadbearing structure, building materials and the remaining part of repair and maintenance), which gives $8.4 + 3.4 + 1.5 = 13.3$. These percentages were then normalised such as to sum to a hundred. Thus, resources are 59%, human-user satisfaction is 26% and technical indicators are 15%. However, this is not an inclusive approach to establishing the relative importance of the three main research variables. In order to cover all cases and furthermore compare and evaluate various opinions, Greek engineers were included in this process. Therefore, a small-scale survey was carried out in Greece, where building engineers and architects were asked to evaluate the three main variables and comment on the GSS percentages. The average of this survey was: resources 42.3%, human-user satisfaction 32% and technical indicators 25.7%. It is interesting to note the significant drop in regard to resources (by almost a third) and the increase in technical aspects. As a result, two sets of weights were developed: one according to the GSS and another according to the engineers.

Having established the coefficient factors of each main variable, as well as the coefficient of the indicators in each main variable, the problem is to relate the performance levels of the qualitative indicators of human-user satisfaction and technical indicators with the quantitative indicators of resources and technical aspects. Therefore, the quantitative resource and technical indicators are processed first, drawing some conclusions on which is the most economical building, the cheapest to run and the fastest to maintain. Next, the qualitative indicators of human-user satisfaction and technical aspects are analyzed and evaluated according to their coefficient. As a result another set of conclusions on the qualitative performance of the buildings is obtained, leading to the identification of both the best and worst structural system in qualitative terms. These sets of conclusions may indicate that a particular structural system is performing better in both cases than the other systems examined. In order to obtain scientific results, the correlation between the two sets of conclusions was examined, resulting in an overall evaluation of the structural systems analyzed. The relative importance of the three main variables facilitated the drawing of inclusive conclusions.

Concluding, it should be noted that each building is examined at three levels: overall, research-related, and envelope. In contrast, information is gathered from all four stages of the building life: briefing, construction design, construction and in-use. Furthermore, the methodology developed appraises the buildings systematically and practically: inclusively and down to earth, collecting information from the users, neighbours, building management team, construction supervisors, architects, engineers and clients as well as from personal observation.

6. Use of Findings

The most important contribution of this particular research project is the development of an inclusive appraising model for long spanning buildings, particularly sports halls and swimming pools. Bearing in mind the results of the literature review and the general lack of inclusiveness in the methodologies developed already, this is the main theoretical use of the findings. It is worth mentioning the work carried out on the actual data processing methodology concerning the problem of integrating qualitative and quantitative data sets for the evaluation of buildings, through development of coefficient factors and relative importance indicators.

The practical use of the findings is their immediate and straightforward application to sports hall and swimming pool buildings in Greece. As the GSS criteria, and consequently the research criteria, are realistic, it is anticipated that the conclusions are going to be of great help and importance for all the clients, designers and engineers concerned with long spanning buildings (especially for conference halls and exhibition centres, where the intrinsic environmental needs are similar). In other words, it is possible to generalize the findings, as the use of the various structural systems is actually the issue under investigation. However, there may be cases where the conclusions of this research constitute only an indicator of the expected performance levels to be obtained with various alternative structural systems.

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