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Critical Factors Influencing the Choice of Frame Type at Early Design

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Abstract : The design process, as defined by Pahl and Beitz (1988), is the intellectual attempt to meet certain demands in the best possible way. Early design phase is a critical part of a building project and decisions made through this phase lay the foundations for the construction phase. These involve the evaluation of alternative frame types fulfilling key constraints in order to come up with the optimum structural solution. Although the choice of frame is heavily influenced by the factors specific to that project, there are a number of issues that are commonly considered by project participants. These issues were addressed by means of literature review, semi-structured interviews and a workshop, to identify the most important factors in influencing structural frame selection. This paper reports on research which analysed postal questionnaires sent to cost consultants, project managers, and clients and established a ranking of ten issues for each stage of early design. The data collected were tested, using the Statistical Package for the Social Sciences (SPSS) through *frequency* and *Spearman's rho* (ρ) analyses. Ten issues proved to be significant to the structural frame selection process; the statistical tests have established the agreement between cost consultants, clients and project managers in the rankings of these issues. Therefore, the paper concludes that these issues could be adopted as fundamental criteria for assessing and selecting the structural frame type for a building project during the early design phase.

Key words: Early design, structural frame, selection criteria.

1. Introduction

The decision on the selection of a structural frame has profound implications for the future performance of a building project. The choice of a structural frame of a building has a major influence on the value to the client, because it provides a high degree of functionality and future flexibility, and can strongly affect the speed of the construction process (SCI, 2000). Furthermore, the frame choice is the key phenomenon of a building project that has a huge impact on both the short- and long-term performance of the completed building. In the short term the frame must give its client the satisfaction of his/her needs such as construction being completed on time and to budget, it must also satisfy future changes in functional requirements of the building in the long term (Soetanto *et al*, 2006). It is therefore significant to recognize the issues that are the most important when choosing the frame type of a building

In this context, this paper reports on research based on a questionnaire survey which ranked the criteria used by project team members when selecting structural frames. The criteria were compiled based on a thorough review of literature on the structural frame selection process, semi-structured interviews and a workshop. The results were analysed using Statistical Package for the Social Sciences (SPSS), and through *frequency analysis*, confirmed that the ten issues were considered to be important by the respondents. The severity index has been further used to rank the issues for the degree of significance. Lastly, *Spearman's rho* (ρ) analysis has been calculated to establish a measure of agreement between cost consultants, clients and project managers in the rankings of issues at early design phase. The study presents findings of a questionnaire survey to establish a ranking of the criteria at the early design and to investigate the degree of agreement among cost consultants, project managers, and clients with regards to the criteria for choosing a frame for a building project. The aim is to present the key issues in order of importance for project team members to consider when choosing an appropriate structural frame for their building projects during the early design phase.

2. The Process of Structural Frame Selection

A structural frame is typically defined as “the load-bearing assembly of beams, columns and other structural members connected together and to a foundation to make up a structure” (Blockley, 2005). According to Soetanto et al, (2006) the structural frame is the skeleton that defines and holds the whole building together. There is a wide choice of structural frame types for building projects. There are four basic types available: *concrete, steel, timber,* or *masonry.* Although many options are available, these tend to be based on structural steel or reinforced concrete frame types for the simplest buildings (Soetanto et al., 2007). Bibby (2006) indicated that the choice of whether to go for a concrete or steel frame is still mainly dependent on building type and site-specific constraints.

Although the choice of frame is heavily influenced by the factors specific to that project, there are a number of issues that are commonly considered by project participants when choosing the frame type. The choice of primary structure is generally determined by cost with less regard to functionality and performance characteristics (SCI, 2000). This is further corroborated by Idrus and Newman (2003) that frame selection criteria often focus on cost and time requirements. However, the cost model studies published by The Concrete Centre (UK) revealed that the structural frame comprises between 7-12% of the final cost of a building in relation to the type of the building (Ryder, 2007). Therefore, The Concrete Centre (2004) suggests that frame cost should not dictate the choice of frame. Many other factors should also be taken into consideration when selecting the optimum frame solution such as programme, health and safety, environmental performance, etc.

The work stages of the RIBA Plan of Work (2007) are used in this research as the stages are well-known and widely recognized throughout the UK Construction Industry. We can consider that ‘early design’ covers design development between RIBA Stages C (Concept) and D (Design Development), and is the phase when the structural frame of a building project is usually selected (Ballal and Sher, 2003). Soetanto et al, (2007) point out the major problem of making decisions based on early designs is the subjectivity which individuals bring to the process. However, the level of a building's performance is largely reflected in the quality of decisions taken in the early stages of the project (McGeorge and Palmer, 2002), hence, the importance of decisions made at the initial design stage is significant since succeeding design tasks, analysis and detailed design generally aim at satisfying the constraints imposed during this formative stage (Ballal and Sher, 2003). Kolltveit and Grønhaug (2004) described the early phase as “the process and activities that lead to, and immediately follow, the decision to undertake feasibility studies and to execute the main project”. Furthermore, the pressure to improve decisions made at the preliminary design process has increased following calls for cost reductions, timely completions, and zero defects in building projects (Egan, 1998; Latham, 1994).

With these pressures in mind a major research study was undertaken to examine key project stakeholders and their views on the structural frame selection process, the methodology for which is described below.

3. Methodology

A comprehensive literature review was first completed in order to collect the key issues from the previous studies in this field. Semi-structured interviews were then conducted with structural engineers to recognize the key issues. Having listed the key issues identified from both the literature and the semi-structured interview’ findings, a facilitated internal workshop with TCC members was intended to generate the final list of ten key issues as being the most important affecting the structural frame selection for a building project with the aim of using them in the postal questionnaire survey. These issues are listed and briefly described in Table 1; the following section describes the methodology used in detail.

Table 1. Key issues influencing the choice of frame type at early design

No	Issues	Explanation
1	Architecture	Aesthetic issues, layout, etc.
2	Building Use/function	Fire resistance, durability, acoustics, Span, Adaptability to later modifications, etc.
3	Cost	Design and Construction Cost
4	Preference	Preference for a particular frame type
5	Programme	Speed of construction
6	Risk	Client needs, the market, expenses, certainty of delivery etc.
7	Site	Site accessibility, ground conditions, height restrictions, party wall agreements.
8	Size of building	Number of floors / m²
9	Supply chain capability	Flexibility in the layout of services, ease of supply of materials
10	Sustainability	Durability, recylability, environmental impacts, thermal mass, whole life cost, etc.

3.1 Interviews

Nine semi-structured interviews were arranged with structural engineers in selected consultancies to retrieve information about structural frame options and how they are evaluated. The core topics discussed during these interviews included: the frame types applied in their projects, influential, criteria used for selecting the frame type, and the rationale behind the preferred frame type of their current project. These interviews were carried out in total over a two-month period at the interviewees' work places, each lasting approximately 30 minutes. Each interview was tape recorded and subsequently transcribed verbatim and analysed. Although the semi-structured interviews found that the choice of frame is heavily influenced by the factors specific to the particular project in hand, a draft, generic list of selection criteria for the choice of frame was developed.

3.2 Internal Workshop

Based on the literature review and the findings from semi-structured interviews, a facilitated half-day workshop with a selection of structural frame specialist staff at The Concrete Centre was held to refine and agree the final list of issues, with the aim of using this in a postal questionnaire survey. The number of issues was necessarily restricted to ten, as shown in Table 1; this was to reflect the level of importance but also to enable the respondents to provide timely responses.

3.3 Questionnaire survey

The list of criteria was then developed into a questionnaire instrument designed to capture practitioners' perceptions of the relative importance of each criterion. The respondents were asked to rate the importance of the criteria on a 4-point Likert scale ranging from 0 for ´lowest level´ to 3 for ´highest level´ as by using an odd number of response points, respondents may be tempted to 'opt-out' of answering by selecting the mid-point (Fellows and Liu, 2003). Having developed the questionnaire, a pilot study was carried out with a sample of nine people from both industry and academia to see how they understand the questions and the response options. Having made a few amendments to the questionnaire as a result of the pilot study, the questionnaire survey was distributed amongst construction clients, cost consultants and project managers to establish the significance and ranking order of the issues identified.

The individual respondents were selected randomly from a database of professional companies held by The Concrete Centre (TCC), regardless of the size of the company. As shown below in Table 2, 239 postal questionnaires were sent to selected names, working for cost managers, project managers and client bodies, in the public and private sectors. As a result, 70 questionnaires were received in total, giving an overall response rate of 29.29% which is considered sufficient enough to meet the research reliability level compared with the norm of 20-30% with regard to questionnaire surveys in the construction industry (Akintoye and Fitzgerald, 2000). Of the responses received, 20 were from cost consultants, 25 from project managers and 25 from clients (Table 2).

Table 2. Questionnaire distribution and response rate

Respondent group	Number of Questionnaires		Response rate %
	Distributed	Returned	
Cost Consultant	86	20	23.26
Project Manager	74	25	33.78
Client	79	25	31.65
Total	**239**	**70**	**29.29**

To ensure each individual's credibility, the respondents were asked about their influence over the choice of frame type for a building project. It was found that 75% of the respondents have a great deal or some influence over the choice of frame type for a building project which suggests that the respondents were generally influential in the structural frame selection, and possessed sufficient knowledge in the structural frame decision-making process.

The results revealed that all of the ten issues included in the list were considered to be important, confirming the validity of the criteria as a basis for consideration in structural frame selection. Because of this, and the considerable degree of influence the respondents have on the choice of frame type, the returned sample was considered to be representative of the actual decision-making population. The next section considers some of the results in detail.

4. Analysis and Results

This questionnaire was designed to provide predominantly descriptive data. An ordinal scale was used to obtain data in this survey that the distances between the numbers (ratings) assigned in the Likert scale were not known. Therefore, non-parametric tests were used in the analysis because non-parametric statistical tests are available to treat data which is inherently in ranks (Siegel and Castellan, 1956; Johnson and Bhattacharyya, 1996); the analysis was then carried out on the ranks rather than the actual data. The non-parametric procedures adopted for this study were frequency, severity index analysis, and Spearman's rho (ρ) test.

First of all, frequency analysis was applied to examine the degree of significance for each issue. The severity index was used to rank the issues for the degree of importance. The results of the frequency analysis and the ranking (severity index) have been based on analyses of all the completed responses. Individuals within these three disciplines provided information based on their own experiences from one of their projects that had recently started on site. However, these experiences were gained from distinct disciplines in the early design phase, so it was essential to conduct a comparative analysis to distinguish between their responses. Since the variables are at the ordinal level, there are two prominent methods for examining the relationship between pairs of ordinal variables namely, *Spearman's rho* (ρ) (or Spearman rank correlation rs) and *Kendall's tau* (τ) – the former being more common in reports of research findings (Brymer and Cramer, 2005). Kendall's tau usually produces slightly smaller correlations, but since Spearman's rho is more commonly used by researchers, it was preferred to be employed in this paper. The Spearman's rho correlation coefficient is produced by using the rank of scores rather than the actual raw data (Brymer and Cramer, 2005; Hinton *et al*., 2004; Kinnear and Gray, 2006). The Statistical Package for the Social Sciences (S.P.S.S.) was used to compute and run these statistical analyses.

4.1 Ranking the key issues: frequency and severity index analysis

This stage of the statistical analysis ranked the issues in order of importance for each stage of early design. In this case, frequency analysis was first carried out to obtain the frequency of the respondents, using the Statistical Package for the Social Sciences (S.P.S.S.). The frequencies of responses were therefore used to calculate severity indices for each issue via Equation 1 (Ballal, 2000):

$$S.I. = \left[\sum_{i=1}^{i=n} \omega i * fi\right] * 100\,\% \,/\, n \qquad [1]$$

Where:

S.I. = severity index $\quad$ fi = frequency of responses

ωi = weight for each rating $\quad$ n = total number of responses

Since the 4-point Likert scale ranging from 0 for ´lowest level´ to 3 for ´highest level´, was used for the survey in order for the respondents not to be tempted to 'opt-out' of answering by selecting the mid-point, the weight assigned to each rating and is calculated by the following Equation 2 (Ballal, 2000):

$$\omega i = \textit{(Rating in scale) / (number of points in a scale)} \qquad [2]$$

$\omega 0 = 0 / 4 = 0$ $\quad$ $\omega 1 = 1 / 4 = 0.25$ $\quad$ $\omega 2$ = No mid-point in the scale

$\omega 3 = 3 / 4 = 0.75$ $\quad$ $\omega 4 = 4 / 4 = 1$

Example: An example of the calculation for the severity index is given below:

Effect of "Architecture" at the Stage C:

	Not Important=0	Of little importance=1	Quite important=2	Extremely important=3	Total (n)
Frequencies (fi)	0	6	31	32	69

Severity Index = ((0*0+6*0.25+31*0.75+32*1)/68)*100 = 82.25**%**

The issues were then ranked in order of value of severity index, the highest value having a rank of 1, and the lowest value assigned a rank of 10. Tables 3 and 4 present the issues ranked in terms of importance for each of the early design stages. 'Cost' appeared to be the most important issue at both stages.

Table 3. Issues ranked in Concept Design

Concept Design (Stage C of RIBA Stages)							
Key issues or criteria	Frequency of responses for score of				No. of responses	Severity Index %	**SPSS Rank**
	0	1	2	3			
Cost	0	3	20	46	69	89.49	**1**
Architecture	0	6	31	32	69	82.25	**2**
Building use/function	0	9	23	37	69	81.88	**3**
Programme	0	10	31	27	68	77.57	**4**
Size of building	1	8	31	25	65	77.31	**5**
Risk	0	14	29	26	69	74.28	**6**
Preference	3	8	40	18	69	72.46	**7**
Site	1	15	27	25	68	72.06	**8**
Sustainability	5	13	27	23	68	68.38	**9**
Supply chain capability	5	27	23	13	68	54.41	**10**

Table 4. Issues ranked in Design Development

Design Development (Stage D of RIBA Stages)							
Key issues or criteria	Frequency of responses for score of				No. of responses	Severity Index %	**SPSS Rank**
	0	1	2	3			
Cost	1	1	17	49	68	91.18	**1**
Architecture	2	2	22	44	70	87.14	**2**
Programme	2	1	31	36	70	85.00	**3**
Building use/function	2	5	24	38	69	82.97	**4**
Risk	1	8	27	33	69	80.07	**5**
Preference	5	6	23	36	70	78.21	**6**
Size of building	2	6	32	26	66	78.03	**7**
Site	2	11	28	28	69	75.00	**8**
Sustainability	5	11	25	28	69	71.74	**9**
Supply chain capability	3	14	28	24	69	70.29	**10**

4.2 Establishing agreement between project managers, cost consultants and clients

To investigate the agreement between three sets of respondents that is to say cost consultants, project managers and clients on the ranking of the key issues, Spearman's rho (ρ) test was applied. The frequency of responses and severity indices were again calculated for each group to produce a separate ranking of the issues, as shown in Tables 5 and 6.

Table 5. Comparison of severity index and ranking for each group at Concept Design

Key issues / Criteria	Concept Design (Stage C of RIBA Stages)					
	Cost Consultant		Project Manager		Client	
	Severity Index %	**SPSS Rank**	Severity Index %	**SPSS Rank**	Severity Index %	**SPSS Rank**
Cost	87.50	**1**	91.67	**2**	89.00	**1**
Architecture	81.25	**2**	80.21	**3**	85.00	**2**
Building use/function	77.50	**3**	92.71	**1**	75.00	**6.5**
Site	76.25	**4**	66.30	**8**	74.00	**8**
Size of building	73.68	**5**	75.00	**6**	82.29	**3**
Risk	71.25	**6**	76.04	**5**	75.00	**6.5**
Programme	70.00	**8**	79.35	**4**	82.00	**4**
Preference	70.00	**8**	67.71	**7**	79.00	**5**
Sustainability	70.00	**8**	54.35	**9.5**	71.00	**9**
Supply chain capability	43.75	**10**	54.35	**9.5**	63.00	**10**

Table 6. Comparison of severity index and ranking for each group at Design Development

Key issues / Criteria	Design Development (Stage D of RIBA Stages)					
	Cost Consultant		Project Manager		Client	
	Severity Index %	**SPSS Rank**	Severity Index %	**SPSS Rank**	Severity Index %	**SPSS Rank**
Cost	92.11	**1**	85.42	**1**	96.00	**1.5**
Architecture	86.25	**2**	79.00	**4**	96.00	**1.5**
Programme	82.50	**3.5**	82.00	**2**	91.00	**3.5**
Risk	82.50	**3.5**	70.83	**6**	87.00	**6**
Building use/function	80.00	**5**	79.17	**3**	89.00	**5**
Preference	78.75	**6**	65.00	**9**	91.00	**3.5**
Size of building	76.32	**7**	71.74	**5**	85.42	**7**
Site	76.25	**8**	69.79	**7**	79.00	**9**
Sustainability	75.00	**9**	67.71	**8**	73.00	**10**
Supply chain capability	70.00	**10**	59.38	**10**	81.00	**8**

From this, Spearman's rho (ρ) (or Spearman rank correlation r_s) test was computed using the Statistical Package for the Social Sciences (S.P.S.S.). The three groups are correlated statistically by applying

Spearman Rho test. Table 7 presents all of the Spearman Rho correlations computed, using SPSS, as shown below.

Table 7. Spearman's Rho (r) test results between the rankings of three groups

Stages of Early Design	**Correlations**		
	Cost Consultant vs. PM	Cost Consultant vs. Client	PM vs. Client
	Correlation Coefficient		
Concept Design (Stage C)	0.732*	0.640*	0.707*
Design Development (Stage D)	0.809**	0.884**	0.640*

Note: ** , * denotes 'strong' with $p < 0.01$ and 'some' with $p < 0.05$ statistical evidence of significant similarities

The level of significance was determined by SPSS both at 0.05 and 0.01 levels, which indicated the degree of relationship amongst the three rankings. While $p < 0.05$ means that there is less than a 5 per cent chance that there is no relationship between the two rankings, $p < 0.01$ can be accepted at the 99% confidence level, assuring that agreement between the two rankings was much higher than it would occur by chance (Bryman and Cramer, 2005; Fellows and Liu, 2003; Field, 2000). From Table 7 above, all of the correlations written with asterisks did achieve statistical significance at either $p < 0.05$ or $p < 0.01$ which confirmed that there are strong relationships amongst the rankings of three groups, particularly at stage D. As a result, it may be concluded that the rankings obtained from the three groups, as given by the severity index analysis, was consensual amongst the respondents.

5. Findings and Discussion

As a result of the frequency and severity index analyses, the ten issues perceived by industry professionals as being the most important in influencing the choice of frame type were ranked in order of importance at each of the early design stages. The Spearman’s rho test established the consensus between the three sets of respondents in relation to the rankings of the issues at each stage.

“Cost”, as anticipated, overrides everything else, indicating that it still dominates structural frame selection. “Architecture” was perceived to be the second most important issue at both stages. ‘Building use/function’ was ranked the third at stage C, indicating the paramount importance of choosing the right type of frame type to suit a given situation. It is plausible that ‘Programme’ rises to be number three at stage D because as the design develops, it becomes a more important consideration. ‘Sustainability’ has a low score which was ranked the second least important issue suggesting that construction practitioners are not taking it seriously. Lastly, the least important issue is ‘Supply chain capability’. However, supply chain capability has significant scores of severity index at the stages C and D, 54.41 and 70.29% consecutively (Tables 3 and 4) which means that it is the least significant only when compared with the other nine key issues.

Table 7 present the Spearman’s rho (ρ) test results which revealed that there was a strong agreement amongst the three groups and the degree of agreement was higher than would have occurred by chance. ‘Cost’ is almost unanimously agreed upon to be the most important issue in the selection of a frame type, apart from stage C where ‘Building use/function’ was ranked highest by project managers. Although the cost consultants, project managers and client were in good agreement with each other with regard to the significance of the ten key issues, their opinions contradict each other in places. The three groups display differences of opinion about 'Building use/function', 'Site', 'Size of building' and 'Programme' at stage C. For instance, rather surprisingly, clients do not consider 'Building use/function' with the same degree of importance as do cost consultants and project managers, a situation that warrants further investigation. Furthermore, cost consultants pay more attention to the importance of 'Site' when compared with project managers and clients. On the other hand, cost consultants attribute less importance to 'Programme' than do project managers and clients (perhaps because they think this is not of concern to them, but more so to contractors and project managers). Regarding the Spearman correlation coefficients in Table 7, agreement is stronger at stage D. However, considering the rankings in Table 6, 'Risk' and 'Preference' are areas of difference amongst the three groups of the respondents, e.g. 'Risk' is ranked higher by cost consultants, clients attribute greater importance on 'Preference', but project managers perceived 'Preference' to be the second least important issue. This raises a question of what makes clients think that 'Preference' plays an important role in the structural frame decision-making progress.

There are certainly some biases and limitations in this study as in any research based on questionnaire surveys. Firstly, with regard to the use of The Concrete Centre's database; although it may not necessarily represent the whole UK construction industry, it is large (25000 names), up to date and nationwide. Secondly, the number of key issues was restricted to ten and these may have been interpreted in a different way by the respondents, despite efforts made to re-phrase the issues after the pilot study.

Nevertheless, it can be said that the ranking of the ten issues obtained from this study adequately does represent the views of the UK Construction Industry in relation to the structural frame selection process. Although the ten issues proved to be considerably important by the views of the respondents to the survey, the general agreement from the literature review was that the selection of frame is often based on the projects' type and specific circumstances (Bibby, 2006). Also, as the literature indicated (SCI, 2000; Idrus and Newman, 2003), 'Cost' was proved once again to be the dominant issue in the structural frame selection process. In addition, client requirements are changing constantly, but they are not communicated to the whole project team resulting in non-conformities and costly changes at the construction phases (Process Protocol, 1998). As clients have become more aware and demanding of the construction industry, they are also becoming less tolerant of the problems and the risks involved in the delivery of major projects (Smith et al., 2004). Therefore, the rank ordering at each stage can give construction practitioners a good indication of the needs and priorities of their clients. Above all, the ranking of these issues at early design phase could be adopted as the fundamental criteria for assessing and selecting the structural frame type for a building project.

6. Conclusions

The early design phase is described in the literature as the process and activities that lead to the decision to execute the main project. Pressure on the industry to improve decisions made at the early design phase, particularly those involving costs and speeds, results in a need for more research in this field. Having undertaken a literature review, semi-structured interviews and a workshop, 10 key issues were identified as being the most important to the structural frame decision-making process. A questionnaire survey was distributed to UK cost consultants, project managers and clients. A total of 70 detailed responses were received and analysed, providing a number of useful insights into the way professionals make choices about structural frame types.

Much of the literature suggested that cost consultants, project managers and clients often have different views about what constitutes success for a building project. However, in this case, the Spearman's rho test statistically revealed that there was strong agreement between three disciplines over the significance of the key issues influencing the choice of a frame type for a building project. Selecting the correct structural framing is crucial to a project's feasibility and success and traditionally, cost is the most influential factor which was confirmed by this research, but architecture was also seen to be important.

It was clear that there were some areas of disagreement between parties, such as sustainability. Aspects such as this are of concern since global issues and regulatory changes are bringing pressure to bear on the construction industry to change its cost-focused attitude. It is clear that the choice of structural frame for a project remains a difficult battle ground for such issues.

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