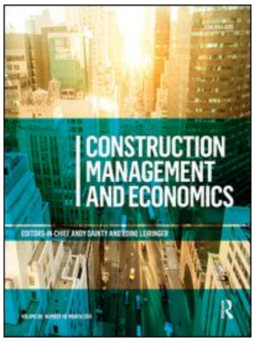

Construction Management & Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

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To cite this article: A. B. Idrus & J. B. Newman (2002) Construction related factors influencing the choice of concrete floor systems, Construction Management & Economics, 20:1, 13-19, DOI: 10.1080/01446190110101218

To link to this article: https://doi.org/10.1080/01446190110101218

Construction Management and Economics (2002) **20**, 13–19

Construction related factors influencing the choice of concrete floor systems

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Received 5 October 2000; accepted 1 October 2001

Designers have a wide choice of concrete floor systems for their buildings. They can choose from three basic types available: *in situ,* precast or hybrid construction. A survey was conducted within the UK construction industry to investigate, in particular, the construction related factors influencing the choice of concrete floor systems. The data collected were subjected to frequency and severity index analyses, Kendall's concordance test and the chi-squared tests to produce a rank ordering of 12 construction related factors. Five factors were identified as being the most important, namely 'appropriateness of use', 'cost', 'constructability', 'speed' and 'health and safety'. These five factors reflect current industry emphasis, and therefore could be adopted as the principal criteria for evaluating and selecting concrete floor systems during the design stage. They could also be used as assessment criteria for developing future systems.

Keywords: Concrete floors, frame construction, selection factors

Introduction

Designers have a wide choice of structural systems for concrete frame buildings. They can choose from three basic types available: *in situ,* precast or hybrid construction. In a concrete frame building, floor construction is the most time consuming and costly element (Domel and Ghosh, 1990; Pessiki *et al.*, 1995; Goodchild, 1997), representing about 70% of the superstructure cost.

The UK concrete frame industry has long been criticized for poor productivity (D'Arcy, 1993; Latham, 1994; Chana, 1996; Egan, 1998; Proverbs *et al.*, 1999), and efforts are being made to improve productivity through design and construction processes. The appropriate selection of floor systems, emphasizing efficiency during construction, can make a significant contribution. In order to develop a rational method for making this selection, factors that are important in influencing the decision need to be established. This would also be helpful in developing new and improved floor systems.

A previous industry survey by Jenks *et al.* (1997) identified several issues perceived to be important in influencing the decision to use hybrid structural systems. Barret and Aouad (1998) adopted the same methodology, and identified general performance criteria for hybrid structures similar to those obtained by the previous investigators. Ballal (2000) analysed postal questionnaires sent to design engineers and contractors, and established a ranking of 17 design and 24 buildability factors important in selecting structural systems.

Compared with steel or timber, concrete floor systems are the more appropriate and popular choice for concrete frame buildings, and some examples are given in Table 1. Often the evaluation and selection of concrete floor systems, carried out mainly during the early design stage, are based on rules of thumb and the experience of the design team. Typically, the evaluation and selection processes would be based on architectural, structural and constructional factors.

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Construction Management and Economics
ISSN 0144–6193 print/ISSN 1466-433X online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/01446190110101218

Table 1 Examples of concrete floor systems

Generic name and structural action	Form(s) of construction
Solid slabs (1or 2-way spanning)	*In situ*
Flat slabs (2-way spanning)	*In situ*
Ribbed slabs (1-way spanning)	*In situ* or precast
Waffle slabs (2-way spanning)	*In situ* or hybrid[a]
Hollowcore slabs (1-way spanning)	Precast
Solid planks (1-way spanning)	Hybrid
Beam and block or pot (1-way spanning)	Precast
Lattice girder permanent formwork (1or 2-Way spanning)	Hybrid
Slim floors (1-way spanning)	Precast or hybrid

[a]Combination of *in situ* concrete and precast concrete, steel or other material.

Each stage of the evaluation eliminates those that, according to the designer's judgement, do not meet the standard minimum performance. The end product of this is a list of two or three selected floor systems to be given more detailed and objective assessment in the subsequent stages of the design, until the best one is found and adopted for the building.

This paper aims to investigate the UK construction industry's views, specifically with regard to construction related factors that influence the choice of concrete floor systems for concrete frame buildings. Factors influencing floor choice as perceived by 41 UK construction industry professionals, mostly consulting engineers and contractors, were analysed. Severity indices were used to rank the factors according to their relative importance. Agreement between the rankings of the two groups was investigated by applying Kendall's concordance test, in conjunction with the chi-square test. Throughout this paper, floor systems will imply concrete floor systems.

Factors influencing the choice of concrete floor systems

A literature review was carried out on the assessment and selection of floor systems. Based on this review and information from industry professionals, a combined list of 29 factors influencing floor choice was produced. These factors, which can be used directly as criteria for evaluating and subsequently selecting floor systems, can be broadly categorized under the headings:

- architectural,
- structural,
- constructional,
- operational,
- environmental, or
- services.

As already stated, only construction related factors were considered in this study, reflecting current industry emphasis. In addition, the factors selected were such that they will be equally applicable irrespective of the form of construction (*in situ*, precast or hybrid). From the original list of 29 factors, 12 were identified as being directly related to the construction process. These are listed and briefly described in Table 2.

Data collection

Industry-wide views on factors influencing the selection of concrete floor systems were obtained by means of a structured postal questionnaire. This method was

Table 2 Construction related factors influencing concrete floor choice

Factor	Brief comments
Familiarity	Familiarity with the construction
Appropriateness of use	Suitability of the floor system with the given frame, considering its structural and constructional limitations. For example, certain kinds of system may suit only regular-grid, or only steel, or only short-span frames, or only when there is good working space available.
Procurement method	Complexity of the procurement
Cost	Construction cost
Speed	Construction speed
Constructability	Ease of the constructing or erecting operations such as simplicity of connections, dimensional precision and repeatability.
Quality of finished concrete	Surface quality
Health and safety	Promotion of health and safety during construction
Supply chain network	Efficiency of supply of materials and services
Labour dependence	Amount of labour needed during construction
Flexibility	Ease of making changes during construction
Accommodation of services	Ease of installation of service ducts

chosen in view of its relatively low cost, and also it gives respondents time to complete the questionnaire and return well considered responses (Foddy, 1988; Fowler, 1988; Leedy, 1989).

Structure of the questionnaire

The questionnaire consisted of three main parts. Part I sought background information about the respondent and their organization. In part II, respondents were asked to rate the level of importance of the 12 construction related factors when making a choice of floor system. The rating was based on a Likert scale of 1–5, where 1 = very low, 2 = low, 3 = moderate, 4 = high and 5 = very high. A reference structure, based on the configuration of the seven-storey European Concrete Building Project in Cardington, Bedfordshire, UK (Goodchild and Moss, 1999) was provided to ensure that respondents used the same base data (Proverbs *et al.*, 1997). Part III sought respondents' assessments of a list of selected concrete floor systems, but a discussion of this is beyond the scope of the present paper.

The respondents

Previous consultations with industry professionals suggested that the majority (85%) of decisions on floor choice is made by consulting engineers (60%) and contractors (25%), with the remaining 15% being made by architects and quantity surveyors. The proportions for the first two groups of professionals tend to support the findings of an earlier investigation on hybrid structures (Barrett and Aouad, 1998). Therefore it was decided to adopt this as the basis for proportioning the sample, so as to represent the actual situation as much as possible.

One hundred and fifty questionnaires were distributed within the UK construction industry to organizations randomly selected from the Kompass Register of Product and Services (Kompass, 1998) and the *New Civil Engineer* Consultant File (ICE, 1998). Of these, 90 were to consulting engineering firms and 45 were to contractors engaged in building construction. The contractors' list also included manufacturers of industrialized floor systems who often operate as subcontractors. The remaining 15 were distributed to architectural practices (10) and quantity surveying firms (5), randomly selected from the same register.

Of the original sample, 41 were returned fully completed. Compared with other similar surveys within the UK construction industry, the response rate obtained (27.3 %) is considered to be good. Of these replies, 25 were from consulting engineers, 14 from contractors, one from an architect and one from a quantity surveyor firm. The proportion of the two primary groups (consultants and contractors) in the returned samples roughly resembles their proportion in making decisions for floor choice. Because of this, and the fact that samples were drawn at random, the returned sample is considered to be representative of the actual decision-making population.

Analysis and results

Data collected from the survey were ordinal in that the distances between the numbers (ratings) assigned in the Likert scale are not known. The ratings in this scale indicate only a rank order of importance of the factors, rather than how much more important each rating is than the other. Using parametric statistics (means, standard deviations, etc.) to analyse such data would not produce meaningful results, and therefore non-parametric procedures must be adopted (Siegel, 1956; Siegel and Castellan, 1988; Johnson and Bhattacharyya, 1996). The non-parametric procedures adopted for this study were frequency and severity index analysis, Kendall's concordance test and the chi-square tests.

Ranking the influencing factors: frequency and severity index analysis

Severity index analysis was conducted on the sample data to rank the factors according to their relative importance. Severity indices rather than mean scores were used since the data were ordinal in nature. In this procedure, frequency analysis was first carried out to obtain the percentage ratings of different selection factors. This was done with the help of the statistical software package 'SPSS' (Statistical Package for Social Sciences). The percentage ratings (given as 'valid percentage' by SPSS) were then used to calculate severity indices via the formula (Elhag and Boussabaine, 1999; Ballal, 2000):

$$\text{S.I.} = \left\{ \sum_{i=1}^{i=n} w_i f_i \right\} \times 100\% \Big/ n \qquad (1)$$

where S.I. is the severity index, *fI* is the frequency of response, *wi* is the weight for each rating(= rating in scale/number of points in a scale), and *n* is the total number of responses. The value (*fi* x 100)/*n* is the valid percentage as calculated by SPSS.

Based on the magnitude of the severity indices, the factors were arranged in descending order as shown in Table 3. There appears to be a relatively large gap separating the following top five factors from the rest:

Table 3 Valid percentage, severity index and ranking for all 41 respondents

Factors or criteria	Valid percentage for score of 1	2	3	4	5	Severity index %	SPSS rank
Appropriateness of use	0	0	7.3	39	53.7	89.28	1
Cost	0	4.9	9.8	41.5	43.9	84.94	2
Constructability	0	0	14.6	48.8	36.6	84.40	3
Speed	0	0	7.3	70.7	22	82.94	4
Health and safety	0	4.9	29.3	36.6	29.3	78.12	5
Accommodation of services	2.5	5.0	42.5	40.0	10.0	70.00	6
Familiarity	2.8	9.8	43.9	31.7	12.2	68.38	7
Quality of finished concrete	0	9.8	46.3	36.6	7.3	68.28	8
Flexibility	2.4	17.1	34.1	41.5	4.9	65.88	9
Supply chain network	5.0	12.5	42.5	32.5	7.5	65.00	10
Labour dependence	4.9	9.8	58.5	17.1	9.8	63.48	11
Procurement method	2.4	19.5	41.5	31.7	4.9	63.44	12

Table 4 Comparison of severity index and ranking for each group

Factors / criteria	Consulting engineers		Contractors	
	Severity index (%)	SPSS rank	Severity index %	SPSS rank
Appropriateness of use	91.2	1	85.8	1
Cost	86.4	2	81.4	4
Constructability	84.0	3	85.8	1
Speed	82.4	4	84.2	3
Health and safety	76.0	5	67.7	9
Accommodation of services	74.4	6	65.6	10
Familiarity	73.6	7	85.6	2
Quality of finished concrete	67.2	8	68.5	8
Flexibility	65.6	9	72.8	5
Supply chain network	64.0	10	59.9	11
Labour dependence	62.4	11	70.7	6
Procurement method	60.0	12	69.9	7

- appropriateness of use,
- cost,
- constructability,
- speed, and
- health and safety.

Investigating agreement: Kendall's concordance test and the chi-squared test

To ensure that the ranking of the factors obtained above was as a result of a consensus agreement between differing factions of the respondents, and also to check how significant this agreement is, two types of statistical test were carried out: Kendall's concordance test and the chi-squared test. Kendall's concordance test was applied to investigate, in holistic terms, the agreement between differing groups within the survey, which were effectively the consulting engineers and the contractors. The percentage ratings and severity indices were again calculated for each group to produce a separate ranking of the factors, as presented in Table 4. From this, Kendall's coefficient of concordance W was computed using the formula (Siegel, 1956):

$$W = \frac{s}{k^2(N^3 - N)/12} \tag{2}$$

where s is the sum of squares of deviation of ranking sum from mean, k is the number of respondent groups (two in this case), and N is the number of factors or entities (12 in this case). Table 5 presents the evaluation of Kendall's concordance coefficient between the engineers' and the contractors' rankings. From the table, Kendall's coefficient of concordance W obtained is 0.78. A coefficient of 0.63 is considered as a moderately high degree of concordance between the sets of ranking (Hays, 1998). Nevertheless, the value of W must also be investigated for significance, to ensure that the agreement between the two rankings (the engineers' and the contractors') were not as a result of pure chance. For this the chi-squared test was used in determining the probability of occurrence of a relationship between the two sets of rankings.

With a concordance coefficient W of 0.78, the chi-squared value obtained was 17.21, for 11 degrees of freedom. Reading from percentage points of the chi-square distribution, the null hypothesis that 'there is no relationship between the sets of ranks' has a probability of occurrence of $p < 10\%$. The alternative hypothesis can therefore be accepted at the 90% confidence level, assuring that agreement among the differing group of respondents was higher than it would be by chance.

Table 5 Derivation of Kendall's concordance coefficient W between engineers' ranking and contractors' ranking, and chi-squared value

Factors/criteria (a)	Engineers ranking (b)	Contractors ranking (c)	Sum of ranking R between groups (b)+(c)	Deviation d of R from mean, m[a] (b)+(c) − (m)	d^2
Familiarity	7.0	3.0	10.0	−3.0	9
Appropriateness of use	1.0	1.5	2.5	−10.5	110.25
Procurement method	12.0	8.0	20.0	7.0	49
Cost	2.0	5.0	7.0	−6.0	36
Speed	4.0	4.0	8.0	−5.0	25
Constructability	3.0	1.5	4.5	−8.5	72.25
Quality of finished concrete	8.0	9.0	17.0	4.0	16
Health and safety	5.0	10.0	15.0	2.0	4
Supply chain network	10.0	12.0	22.0	9.0	81
Labour dependence	11.0	7.0	18.0	5.0	25
Flexibility	9.0	6.0	15.0	2.0	4
Accommodation of services	6.0	11.0	17.0	4.0	16
Kendal's concordance coefficient $W = 12s/(k^2(N^3 - N)) = 0.78$[b]					
Chi-squared value = $\chi^2 = k(N-1)W = 17.21$					

[a]m, mean of R = (10 + 2.5 + 20 … + 17)/12 = 13.
[b]s is the sum of squares of deviation of R from mean = $\sum d^2 = 447.5$; k is the number of ranking groups = 2; and N is the number of factors = 12.

Thus we may conclude that the ranking obtained for all the 41 respondents, as given by the severity index analysis, was consensual among the respondents, significant and coherent, and therefore may be used for research.

Discussion

The statistical analysis carried out has systematically ranked a list of 12 construction related factors perceived by industry professionals as being important in influencing the choice of floor system. The ranking obtained (Table 3) was as a result of a consensual agreement among the respondents, as confirmed by the concordance test. A visual inspection of the ratings also shows that none of the respondents had used the same rating for all the factors throughout, implying that thoughtful consideration had been given to the questionnaire.

'Appropriateness of use', as expected, was ranked highest, indicating the utmost importance of choosing the right kind of floor system to suit a given situation. 'Cost', which has been and will continue to be a major objective for any engineering decision, was perceived to be the second most important factor for the selection of a floor system. This is followed by 'constructability' and 'speed', but judging from their severity indices, the percentage differences between 'cost', 'constructability' and 'speed' are very small (less than 2%, measured relative to the higher ranked factor). Thus, one could perhaps give them *equal* importance. All the above four factors are among the important issues raised in his report by Egan (1998), who called for improved competitiveness, better value for money and predictability in UK construction projects. The fact that the survey was conducted after that report was published might indicate a positive reaction towards the report by the respondents, and therefore is thought to be the underlying reason for the choice of the above factors. This may be confirmed by looking at the position of 'health and safety', another important but relatively new issue raised in the report, as the fifth most salient factor influencing the choice of a floor system.

Professional background and training may also have an influence on the selection of the factors. Although, as a whole, UK engineers and contractors are in good agreement with each other with regard to the ranking of the factors, their opinions somehow contradict each other, particularly on some of the lower ranked factors. For example, considering the rankings in Table 4, contractors do not view 'health and safety' in floor construction with the same degree of importance as do engineers, a situation that can be a cause for concern for the industry. In addition, contractors (in the survey, frame contractors) also pay less attention to the importance of efficiency of floor systems in accommodating service ducts. This may be because they do not see the importance of this issue in design as much as the engineers, or because they may think that this is a problem for the structural or mechanical and electrical engineers. Engineers, on the other hand, perceive 'familiarity' to be less important in influencing the choice of a floor system when compared with contractors. Making decisions based on familiarity and personal preferences is perhaps something engineers are quite reluctant to admit, even though in reality this has been known to be a common practice.

Rather surprisingly, 'quality of finished concrete' is not ranked highly by the respondents (ranked 8th out of 12). The engineers' and contractors' rankings for this factor (Table 4) show that engineers and contractors have the same view on its importance. A possible reason for this is that quality, though very important in floor construction, is more a function of workmanship and material specification, rather than the *type* of system chosen. Besides, this low ranking could also be attributed to the increased use of false ceilings and raised floors in modern buildings, as commented by some of the respondents.

It is also interesting to note that labour dependence causes much less concern to the industry (ranked 11th out of 12). This can be an indication that construction labour in the UK is still abundant.

As in any research work based on surveys, the study is subject to certain biases and limitations. Firstly, the assessment of the factors was restricted to those stated in the questionnaire. Although respondents were encouraged to add their own, these could not be added to the original list because only a few of them did so and each gave a different one. Secondly, the engineers were chosen from the private (consultant) sector only. Public sector engineers such as those in local authorities should have been included in the sampling list, as some of their projects are designed 'in-house'. Finally, this study is limited to investigating construction related factors only. In practice, the choice of the floor systems will also be influenced by factors from other categories, such as structural, architectural, services or operational, depending on the emphasis placed in the selection.

Despite the above limitations, the authors are of the opinion that the factors in ranking order obtained from this study adequately represent the views of the construction industry with regard to the construction related factors affecting the choice of floor or similar structural systems. The rank ordering of the salient factors (appropriateness of use, cost, constructability, speed, and health and safety) can help those engineers in the industry involved in the development of procedures or computer-based tools for the evaluation and selection of floor and other structural systems. They are able to prioritize the criteria that should be taken as the basis of evaluation and selection by their system and, consequently, determine the data to be collected.

Researchers and design engineers working towards developing new and more efficient floor systems, such as those in the precast manufacturing sector of the industry, should also find the factors useful. The factors would give them a good indication of the needs and priorities of their 'customers' (i.e. the decision-makers of floor systems). By focusing their inventions according to the factors, not only would they receive wider acceptance of their products in the market but also they would improve the availability of construction-efficient and higher quality structural components. With wider and more frequent use of such systems, it is envisaged that the overall performance of UK construction projects and therefore the overall productivity in the UK construction industry could be improved, in line with the Egan aspirations.

Conclusion

Following a literature review on methods of assessing and selecting floor systems, 12 factors were identified as being directly related to the construction process. A structured questionnaire survey was conducted within the UK construction industry to obtain data on the perceived importance of these factors with regard to the choice of a concrete floor system. A non-parametric method was used to analyse the data and from this, and a consensual ranking of the factors was produced.

The ranking shows that 'appropriateness of use' is perceived to be the principal selection factor, followed by, in order of importance, 'cost', 'constructability', 'speed' and 'health and safety', i.e. five factors that seem to reflect current industry emphasis. These five factors may be adopted as the criteria for evaluating and selecting concrete floor systems during the design stage. In addition, they may be used as criteria for the development of future improved floor systems.

Acknowledgement

The authors would like to thank all the organizations that had spent their valuable time to complete and return the questionnaire. Without their co-operation, this research would not have been possible.

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