Information priority-setting for better resource allocation using analytic hierarchy process (AHP)

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Abstract
Focuses on the use of analytic hierarchy process (AHP) to prioritize different forms of information. Identification of the key information may help better allocation of resources for a construction project. Various forms of information and their associated activities may critically affect the project, which have to be carefully dealt with for enhancing the project performance. Essentially, when some of these forms of information have to be produced and managed by more sophisticated information technology, the more we know about their importance level, the better we could allocate our investment in the construction project. In general, this study reveals that managerial information is equally as important as technical information. This implies that an overall information system should incorporate the technologies and techniques for generating and maintaining both types of information.

Introduction

Construction projects require different forms of information, such as the scope definition, details of design, project schedule, etc., for integrating the diversified tasks and activities, leading to the production of the final product. It is understood that information is one of the major impacts that, in a construction project, affect communication (Ndekugri and McCaffer, 1988; Pietroforte, 1997) and coordination (Howard and Rehak, 1989; O'Brien *et al.*, 1995). Therefore, it is critical to enhance communication and coordination, resulting in not only better linking the construction parties for completing the construction project but also improving business performance of the involved parties leading to overall project performance in terms of time, cost, schedule, quality and value.

Identification of the key information may help better allocation of resources for a construction project. It is because different forms of information have different degrees of importance that some of them may critically affect the project and have to be carefully dealt with for enhancing the project performance. Essentially, when some of this information is produced and managed by more sophisticated information technology, the more we know about its importance level, the better we can allocate our investment and resources in the construction project.

Weighting is a solution to identify the key information. In the absence of a weighting instrument, measuring the relative weights of the sources is acceptable (Saaty, 1994). This usually relies on the subjective judgments made by decision makers and/or experts. A simple method is to guess each element according to an absolute rating scale, and compare it with other elements in the whole set by dividing its weight by the total to get its relative weight, where those with heavier weights are key elements. However, such a simple rating method cannot detect whether the respondents provided their answers arbitrarily or carelessly. Also the method cannot determine if the respondents are the real experts. In other words, the traditional rating method cannot filter out inconsistency of responses.

Recently, analytic hierarchy process (AHP) has been increasingly used to assign weights to tested elements. It is a structured method that can elicit more information from target respondents (usually experts or decision makers). It outweighs the simple rating method as it helps to ascertain the consistency of responses. On the other hand, the ranking of industrial projects using AHP has been raised to help management in efficient allocation of companies' resources (Alidi, 1996). Similarly, ranking of the construction information may provide additional insight in allocating scarce resources, especially the impact on information technology for designing a cost-effective and economic way to information management. Therefore, identification of the key construction information is crucial.

This paper is intended to weight different forms of information required for a construction project so that the key construction information can be determined, resulting in better resource allocation. The paper presents how the AHP method can achieve the research objectives. The paper also serves to highlight some critical issues in using AHP.

The AHP method

AHP has become quite popular in research due to the fact that its utility outweighs that

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of other research methods. AHP considers both qualitative and quantitative approaches to research and combines them into a single empirical inquiry. The development of AHP can be traced back to the early 1970s, in response to the scarce resources allocation and planning needs for the military (Saaty, 1980). As the methodological procedure of AHP can easily be incorporated into multiple, objective programming formulations with interactive solution process (Yang and Lee, 1997), it has received wider attention in various fields. Using the area of construction as an example, a recent literature review paper in construction partnering has raised the use of it in construction research (Li *et al.*, 2000). Moreover, Chua *et al.* (1999) used AHP to identify the critical factors conducive to the success of construction projects. McIntyre *et al.* (1999) applied the AHP method to determine a weighed scale for selecting a divisional director for a construction party. Saaty (1990) refers to the former as the relative measurement function of AHP and the latter as the absolute measurement function.

Specifically, AHP aims at assigning weights to tested elements. Weighting of elements has two major functions. First, it helps to prioritize (rank) elements so that the key elements can be determined. Second, as it helps to identify the key elements, it can be used to make more accurate business decisions, such as formulation of information management strategies and investment of appropriate technology for key business practices.

AHP is a hierarchical representation of a system. A hierarchy is an abstraction of the structure of the system, consisting of several levels representing the decomposition of the overall objective to a set of clusters, sub-clusters, and so on, down to the final level which would usually be the alternatives or scenarios to be selected. The clusters or sub-clusters can be forces, attributes, criteria, activities, objectives, etc.

AHP elicits opinions from experts or decision makers. It has two advantages. First, it adopts a pair-wise comparison process by comparing two objects at one time to formulate a judgment as to their relative weight. Second, with an adequate measurement, this method is more accurate (with less experimental error) to achieve a higher level of consistency since it requires the respondents to think precisely before giving their answers. Usually, the more a person knows about a situation, the more consistent the results that can be expected from this person.

Moreover, the AHP method employs the consistency test that can screen out inconsistent responses. Inconsistency refers to a lack of transitivity of preferences (Saaty, 1980). Those respondents who could not build up their judgements logically would not achieve the consistent comparisons. The following is an eight-step AHP method that is used in this paper:

1. *Defining the decision problem.* The decision problem should be defined clearly since it drives the whole AHP method. Those involved should clearly explain what their problems are and why AHP has to be used.
2. *Developing a conceptual framework.* This involves decomposing the complexity of a problem into different levels or components and synthesizing the relations of the components.
3. *Setting up the decision hierarchy.* Such a chain of hierarchy represents the system of the problem. It may consist of several levels and different groups of related elements.
4. *Collecting data from experts.* It is noted that the AHP approach is a subjective methodology. Data are obtained by directly questioning the experts on the subject matter.
5. *Employing the pair-wise comparison.* All elements are compared using the priority scale pair by pair. A paired comparison or judgement matrix is formed. It is suggested that Saaty's scale of measurement be used to rate the intensity of importance between two elements, which is shown in Table I (Saaty, 1980).
6. *Estimating relative weights of elements.* After the pair-wise comparison matrix is developed, a vector of priorities (i.e. a proper or eigen vector) in the matrix is calculated and is then normalized to sum to 1.0 or 100 per cent. This is done by dividing the elements of each column of the matrix by the sum of that column (i.e. normalizing the column). Then, obtaining the eigen vector by adding the elements in each resulting row (to obtain "a row sum") and dividing this sum by the number of elements in the row (to obtain "priority weight").
7. *Calculating the degree of consistency.* It is known that people are often inconsistent in answering questions, and thus one of the important tasks of AHP is to calculate the consistency of the responses. In order to validate the responses, a consistency test is employed. This test will be described in more detail in a later section.
8. *Calculating the mean relative weights.* If there is more than one response having acceptable consistency, the mean relative

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weights from all responses for each set of elements are calculated to obtain a composite view for analysis.

Conceptual framework for structuring construction information

The decision problem of this paper has been presented in the Introduction section. In this section, a conceptual framework for structuring construction information is developed. Specifically, the decomposition of a problem refers to the aggregation of similar information into different groups, while the synthesis of relations is the integration of them in a systematic way. This involves defining what information flows through the boundaries of partners within the construction network, and classifying them. Since construction information is so ubiquitous, classifying information helps to justify the right amount of information for a particular user, avoiding redundant information that is of no value to that user (Zamanian and Pittman, 1999). Classification of information has been attempted by some organizations such as the International Organization for Standardization (ISO) (1993) and the Institute of Civil Engineers (ICE) in the UK (*Civil Engineering Standard Method of Measurement*, 1991) and researchers including Hanlon and Sanvido (1995) and Kang and Paulson (1997). Cheng *et al.* (1999), based on these two processes, developed a framework for structuring construction information. The decision hierarchy is established based on the following procedure:

- To divide information into either managerial or technical categories.
- To split information into the five different phases of a construction project.
- To classify the construction information with cross-combination of the results from the above two steps.

A construction project involves the transmission of both managerial and technical information for the completion of different operational activities and tasks. It is generally accepted that evaluations that take place at the operational level will be more realistic (Saaty, 1980). Moreover, managerial information refers to those kinds of information that assist in management of construction work. As Hassan *et al.* (1998) suggested, managerial information is required for maintaining project planning, analysis systems, document control, communication systems, finance and accounting. Technical information, on the other hand, specifies the construction material, design, and methods to be used in a project. For example, design consultants require technical information for modeling and calculations, while contractors require it for materials procurement and calculations (Hassan *et al.*, 1998). In general, technical information is presented mainly in technical terms. This includes appropriate software applications that support different techniques required by various discipline specialists.

On the other hand, Pietroforte (1997) argued that information is transferred in a one-off large batch from one construction phase to another. Since a construction project consists of several phases, each therefore consists of its own operational activities and tasks that require specific forms of information to complete (Tah *et al.*, 1998). This paper follows Saad and Hancher (1998) who suggested that a construction project is divided into five main phases, which are planning, design, procurement, construction, and commissioning. The structure of construction information classification is shown in the Appendix.

Table I
Saaty's scale of measurement in pair-wise comparison

Intensity of Importance (1)	Definition (2)	Explanation (3)
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one over another
5	Strong importance	Experience and judgement strongly favor one over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to represent compromise between the priorities listed above
Reciprocals of above non-zero numbers		If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

Source: Saaty (1980)

Setting up the decision hierarchy

The decision hierarchy is formed based on the conceptual framework, and resembles the structure as shown in the Appendix. This kind of usage has been attempted by Tan and Lu (1993) who used AHP for prioritizing the criteria and factors affecting the quality of construction engineering design projects. The formation of the hierarchy is based upon two assumptions, without which a problem cannot be dealt with using AHP:

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1 It is expected that each element of a level in the hierarchy would be related to the elements at the adjacent levels. AHP recognizes the interaction between elements of two adjacent levels.
2 There is no hypothesized relationship between the elements of different groups at the same level.

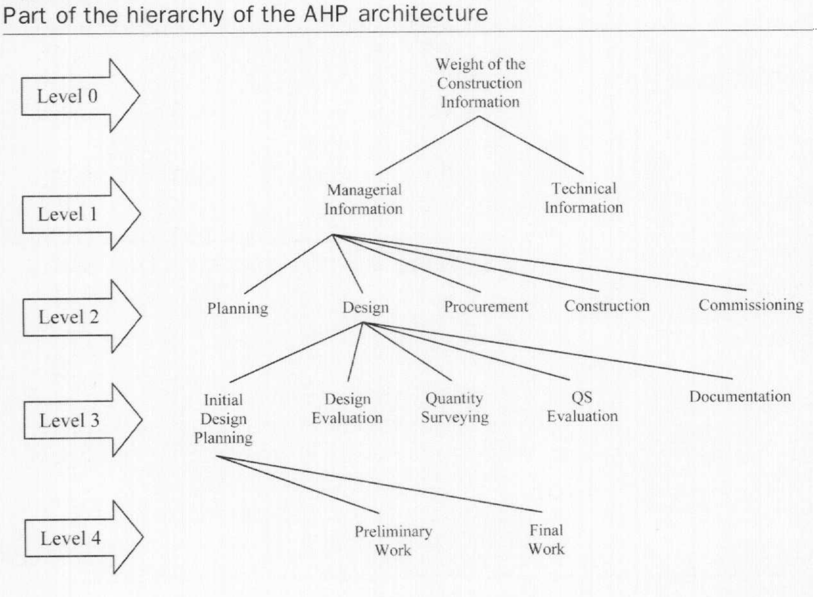
This reiterates that a problem should be clearly defined. In this paper, as the kinds of information identified for managerial or technical areas or for different project phases are independent from each other, this has conformed to the assumptions for building the hierarchy. A schematic representation of part of the hierarchy of the weight of information is shown in Figure 1. This hierarchy shows the information required for the activities/tasks identified in the initial design planning of the design phase. It consists of five levels and starts from the zero level, i.e. weight of the construction information, which is the core problem of this study. It is then broken up into managerial and technical information, which forms the first level. The five phases of a project form the second level. The fourth level consists of the preliminary and final work of the initial design planning (IDP), which is an element of the third level derived from the design phase at the second level.

Methodology

Data collection and findings

A questionnaire was designed according to the decision hierarchy. Related elements were grouped together to form a matrix for pair-wise comparison. Two experts who were actively involved in a construction project were invited to complete the questionnaire. They represented two different major professions (architecture and engineering) in the construction industry. Although opinions from two experts may only provide a very rough picture, it is still appropriate in this exploratory study. Also, it is noteworthy that AHP does not necessarily involve a large sample (Lam and Zhao, 1998). After the pair-wise comparison matrix was developed, the relative weights of the elements on each level in the hierarchy of the two usable questionnaires were computed and shown in Table II. Columns 3 and 5 of the table are the relative weights estimated by the two experts on the four levels (i.e. the types of information, construction phases, and sub-phase/information required for operational activities) of the hierarchy respectively.

Figure 1
Part of the hierarchy of the AHP architecture



Consistency test

Consistency ratio (CR) is used to measure the consistency in the pair-wise comparison. Saaty (1994) has set the acceptable CR values for different matrices sizes: the CR value is 0.05 for a 3-by-3 matrix; 0.08 for a 4-by-4 matrix; and 0.1 for larger matrices. If the consistency level falls into the acceptable range, the weight results are valid. Crowe *et al.* (1998) provided a procedure, which is adapted from Canada and Sullivan (1989), for calculating the consistency ratio:

1 Calculate a new vector "*C*" by multiplying the pair-wise comparison matrix "*A*" on the right by the estimated solution vector "*B*". In mathematical terms, the equation for multiplying the matrix A (a_{ij}), vector B (b_j) to obtain vector C (c_i) is:

$$c_i = \sum_{j=1}^{n} a_{ij}\, b_j \qquad (i = 1, 2, \ldots, n)$$

2 Calculate the eigen vector "*D*" by dividing the vector "*C*" by its corresponding element in vector "*B*".
3 Calculate the maximum eigenvalue (λmax) by averaging the numbers in vector "*D*".
4 Calculate the consistency index (CI) for a matrix of size n according to the formula: CI = $(\lambda\max - n)/(n - 1)$.
5 Calculate the consistency ratio (CR) using the formula: CR = CI/RI where RI is the random index for the matrix size, n. Table III is a random index table which is obtained by approximating random indices for matrices of order 1 to 10 using a sample size of 500 (Saaty, 1980).

If the CR is greater than the acceptable value, this empirically reveals excessive

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Table II
CR values and relative and mean weights for the hierarchy

Construction information source (1)	CR value for A (2)	Relative weight for A (3)	CR value for B (4)	Relative weight for B (5)	Mean weight for A&B (6)
Level 1:					
1 Managerial information	n.a.	0.50	n.a.	0.50	0.500
2. Technical information		0.50		0.50	0.500
Level 2:					
1.1 Planning	0.031	0.18	0.036	0.15	0.165
1.2 Design		0.18		0.29	0.235
1.3 Procurement		0.09		0.07	0.080
1.4 Construction		0.53		0.44	0.485
1.5 Commissioning		0.04		0.05	0.045
2.1 Planning	0.022	0.10	0.071	0.13	0.115
2.2 Design		0.38		0.38	0.380
2.3 Procurement		0.05		0.13	0.090
2.4 Construction		0.38		0.25	0.315
2.5 Commissioning		0.10		0.13	0.115
Level 3:					
1.1.1 Construction initialization	n.a.	0.25	n.a.	0.50	0.375
1.1.2 Initial planning		0.75		0.50	0.625
1.2.1 Initial design planning	0.007	0.28	0.028	0.48	0.380
1.2.2 Design evaluation		0.28		0.24	0.260
1.2.3 Quantity surveying (plus resourcing)		0.09		0.10	0.095
1.2.4 QS evaluation		0.28		0.10	0.190
1.2.5 Documentation		0.07		0.08	0.075
1.3.1 Tendering	0.000	0.43	0.010	0.59	0.510
1.3.2 Directing		0.14		0.12	0.130
1.3.3 Scheduling		0.43		0.29	0.360
1.4.1 General contractor	0.049	0.39	0.071	0.36	0.375
1.4.2 Sub-contractors		0.08		0.12	0.100
1.4.3 Workers		0.06		0.04	0.050
1.4.4 Management		0.39		0.36	0.375
1.4.5 Surveying duties		0.08		0.12	0.100
2.2.1 Layout	0.013	0.09	0.047	0.06	0.075
2.2.2 Preliminary design		0.18		0.28	0.230
2.2.3 Analysis		0.09		0.11	0.100
2.2.4 Detailed design		0.45		0.33	0.390
2.2.5 Designing		0.18		0.22	0.200
2.4.1 Periodic valuations	0.081	0.05	0.052	0.10	0.075
2.4.2 Site production planning		0.24		0.10	0.170
2.4.3 On-site production		0.33		0.38	0.355
2.4.4 Constructability		0.24		0.38	0.310
2.4.5 Plant		0.14		0.05	0.095
Level 4:					
1.2.1.1 Preliminary work	n.a.	0.17	n.a.	0.33	0.250
1.2.1.2 Final work		0.83		0.67	0.750
1.4.1.1 Site related activities	0.000	0.38	0.030	0.55	0.465
1.4.1.2 Construction's operation information		0.38		0.25	0.315
1.4.1.3 Subcontractors' information		0.13		0.09	0.110
1.4.1.4 Suppliers' information		0.13		0.11	0.120
1.4.3.1 Shortage information	0.003	0.65	0.016	0.55	0.600
1.4.3.2 Conditions of work		0.23		0.21	0.220
1.4.3.3 Competence of workforce		0.12		0.24	0.180
1.4.4.1 Management attitude	n.a.	0.50	n.a.	0.50	0.500
1.4.4.2 Management policy		0.50		0.50	0.500
2.4.3.1 Surroundings	0.000	0.14	0.077[a]	0.14	0.140
2.4.3.2 Usable work area		0.43		0.14	0.285

(continued)

Table II

Construction information source (1)	CR value for A (2)	Relative weight for A (3)	CR value for B (4)	Relative weight for B (5)	Mean weight for A&B (6)
2.4.3.3 Organization on-site		0.43		0.71	0.570
2.4.4.1 Design issues	0.048	0.07	0.086	0.06	0.065
2.4.4.2 Unavailability of information		0.33		0.33	0.330
2.4.4.3 Errors and omissions		0.20		0.22	0.210
2.4.4.4 Poor workmanship		0.20		0.17	0.185
2.4.4.5 Sub-standard materials		0.20		0.22	0.210
2.4.5.1 Delay problems	0.048	0.14	0.062	0.21	0.175
2.4.5.2 Operator		0.07		0.21	0.140
2.4.5.3 Appropriateness of chosen plant		0.69		0.41	0.550
2.4.5.4 Theft and vandalism		0.03		0.07	0.050
2.4.5.5 Insufficient space for plan operation		0.07		0.10	0.085

Notes:
A and B are the two respondents respectively.
[a] denotes that only this CR value (0.077) in the two usable questionnaires was less than the acceptable value for a 3-by-3 matrix (0.05) according to Saaty (1994). However, this value has already passed an acceptable value (0.10) that was recommended by Saaty (e.g. 1980, 1990) in his earlier publications and was widely adopted in many papers using the AHP method. So, this prioritized matrix was still analyzed in this paper and the mean values of the weighting results of the two usable questionnaires were computed.
n.a. = not applicable. The CR value could not be computed for a 2-element matrix due to the limitation of the equation. However, a 2-element matrix has a perfect consistency.

Table III
Average random index values[a]

Size of matrix (1)	Average RI (2)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Source: [a] Saaty (1980)

intransitivity of preferences. CR provides a very good estimation of the consistency of the respondents in answering the questions.

Since the two responses had acceptable consistency, they were then aggregated to obtain the combined judgements on the weight of the elements at each hierarchy level. Table II exhibits the results. Columns 2 and 4 of the table show the CR value of each group of elements at each level of the decision hierarchy from the two responses respectively, while column 6 is their mean relative weights.

Discussions

The two experts (representing two key construction professions: architecture and engineering) giving similar responses may imply that their opinions are likely to be useful to the industry. It is essential to discuss the weighting results as follows:

- The survey results indicate that both respondents thought that managerial and technical information were equally important. In the past, technical information was treated as more important. This phenomenon has been changed recently, particularly after a widespread emphasis of management on construction in the industry. This reminds us that an information system must be designed which takes into consideration both managerial and technical information. How to produce and maintain the system are equally important. Aouad *et al.* (1998) suggested that in order to improve managerial and technical work for various stages of a project, a variety of technologies, including project simulation, multi-media applications, neural network, robotics, etc., should be applied to generate and maintain managerial and technical information.
- The survey results also indicate that the phases of construction and design were very important in both types of work. Specifically, the level of importance of managerial information in the construction phase (0.485) was twice as much as that in the design phase (0.235). It is understood that the construction phase involves different construction

professionals and larger amounts of people than the design phase. Thus, a lot of management activities have been organised during construction, which have to be completed with heterogeneous managerial information. Without such information, poor management of work will result in, to a small extent, a rework or claim, or even possibly a total eclipse of the project. For technical information, the design phase (0.380) was slightly more important than the construction phase (0.315). It is noteworthy that the design phase is composed of architectural as well as structural designs involving plenty of technical information. Although technical information is essential in the construction phase, it is a stage of applying rather than creating information.

- The results further reveal that initial design planning and design evaluation were the two most important forms of managerial information in the design phase, while quantity surveying information was less important comparatively. On the other hand, in the construction phase, managerial information for the general contractor and management function was more important; unexpectedly, information for surveying duties was less important. However, it is interesting to note that the two respondents were design consultants and might have biases on the answers that favor their professions.
- Other findings show that, in the construction phase, technical information was more important for the on site production and for evaluating constructability. Design consultants are expected to have a very close contact with the general contractor, to ensure the correct and updated technical information for on site production. Also, information for organizing work on site and showing usable work area was more essential to influence on site production. For improving the construction phase, technical information for evaluating constructability is argued to be crucial. Unavailability of information was a critical barrier to evaluate constructability, whereas information about errors and omissions, sub-standard materials or poor workmanship is critical to improve constructability.

In general, this example reveals that managerial information is equally as important as technical information. It implies that an overall information system should incorporate the technologies and techniques for generating and maintaining both types of information. Such a system has been raised by different groups of researchers (e.g. Sarshar *et al.*, 1994; Ahmad *et al.*, 1995; Rezgui and Debras, 1995; Cheng *et al.*, 1999), whereas the associated techniques have been described by Aouad *et al.* (1998). Among the five major project phases, design and construction phases are more received by the two participated experts, implying that they are more important than other phases. This finding is similar to our literature review – that published research papers have focused primarily on information problems in these two phases (e.g. Shapira and Retik, 1996; Baldwin *et al.*, 1999).

It is noted that in the past researchers in the field of construction information technology have provided solutions for handling technical information (e.g. Ford *et al.*, 1995; Tah *et al.*, 1998). Since construction organizations need to expand their ability to overcome the problems arising from increasingly sophisticated managerial information, solutions for dealing with managerial information have emerged (e.g. Kelly *et al.*, 1997; Agapiou *et al.*, 1998; Rezgui and Cooper, 1998).

Conclusions

This paper is intended to introduce the use of AHP in weighting the information for a construction project. The construction information is classified based on two main criteria. First, it can be managerial or technical. Second, the five phases of a construction project – planning, design, procurement, construction, and commissioning – need different forms of information. AHP considers both qualitative and quantitative approaches to research and intends to combine them into a single methodology. More specifically, it uses a qualitative way to decompose an unstructured problem into a decision hierarchy and induces an iterative process to solve any inconsistent responses. On the other hand, it employs pair-wise comparison with a prescribed absolute scale and performs the consistency test to validate the consistency of respondents. This paper presents an eight-step AHP method, which includes the use of consistency test. Essentially, it explains how the identification of key construction information helps in better allocation of resources for a construction project. It reflects the increasing importance of managerial information that forms a key role in the design of an integrated information system.

Finally, the study finds that the consistency test is useful to ascertain the consistency of responses.

References

Agapiou, A., Flanagan, R., Norman, G. and Notman, D. (1998), "The changing role of builders merchants in the construction supply chain", *Construction Management and Economics*, Vol. 16, pp. 351-61.

Ahmad, I., Russell, J.S. and Abou-Zeid, A. (1995), "Information technology (IT) and integration in the construction industry", *Construction Management and Economics*, Vol. 13, pp. 163-71.

Alidi, A.S. (1996), "Use of the analytic hierarchy process to measure the initial viability of industrial projects", *International Journal of Project Management*, Vol. 14 No. 4, pp. 205-8.

Aouad, G., Hinks, J., Cooper, R., Sheath, D.M., Kagioglou, M. and Sexton, M. (1998), "An information technology (IT) map for a generic design and construction process protocol", *Journal of Construction Procurement*, Vol. 4 No. 2, pp. 132-50.

Baldwin, A.N., Austin, S.A., Hassan, T.M. and Thorpe, A. (1999), "Modelling information flow during the conceptual and schematic stages of building design", *Construction Management and Economics*, Vol. 17, pp. 155-67.

Canada, J.R. and Sullivan, W.G. (1989), *Economic and Multiattribute Evaluation of Advanced Manfacturing Systems*, Prentice-Hall, Englewood Cliffs, NJ.

Cheng, E.W.L., Li, H., Love, P.E.D. and Irani, Z. (1999), "The development of a conceptual framework for structuring information in construction projects", *9th Annual BIT Conference: Business Information Technology Management Generative Futures*, November 3-4, CD-ROM, The Manchester Metropolitan University, Manchester.

Chua, D.K.H., Kog, Y.C. and Loh, P.K. (1999), "Critical success factors for different project objectives", *Journal of Construction Engineering and Management*, Vol. 125 No. 3, pp. 142-50.

Civil Engineering Standard Method of Measurement (1991), 3rd ed., Thomas Telford, London, pp. 4-39.

International Organization for Standardization (1993), "Classification of information in the construction industry", *ISO Tech. Rep., ISO TC 59 SC/WG2*. International Organization for Standardization, Oslo.

Crowe, T.J., Noble, J.S. and Machimada, J.S. (1998), "Multi-attribute analysis of ISO 9000 registration using AHP", *International Journal of Quality & Reliability Management*, Vol. 15 No. 2, pp. 205-22.

Ford, S., Aouad, G., Kirkham, J., Brandon, P., Brown, F., Child, T., Cooper, G., Oxman, R. and Young, B. (1995), "An information engineering approach to modelling building design", *Automation in Construction*, Vol. 4, pp. 5-15.

Hanlon, E.J. and Sanvido, V.E. (1995), "Constructability information classification scheme", *Journal of Construction Engineering and Management*, Vol. 121 No. 4, pp. 337-45.

Hassan, T.M., Thorpe, T. and McCaffer, R. (1998), "Client business and IT requirements of the European construction industry", *International Journal of Construction Information Technology*, Vol. 6 No. 2, pp. 1-26.

Howard, H.C. and Rehak, D.R. (1989), "KADBASE: a prototype expert system-database interface for engineering", *IEEE Expert*, Vol. 4 No. 3, pp. 65-76.

Kang, L.S. and Paulson, B.C. (1997), "Adaptability of information classification systems for civil works", *Journal of Construction Engineering and Management*, Vol. 123 No. 4, pp. 419-26.

Kelly, J.G., Aouad, G., Rezgui, Y. and Crofts, J. (1997), "Information systems developments in the UK construction industry", *Automation in Construction*, Vol. 6, pp. 17-22.

Lam, K. and Zhao, X. (1998), "An application of quality function deployment to improve the quality of teaching", *International Journal of Quality & Reliability Management*, Vol. 15 No. 4, pp. 389-413.

Li, H., Cheng, E.W.L. and Love, P.E.D. (2000), "Partnering research in construction", *Engineering, Construction and Architectural Management*, Vol. 7 No. 1, pp. 76-92.

McIntyre, C., Kirschenman, M. and Seltveit, S. (1999), "Applying decision support software in selection of division director", *Journal of Management in Engineering*, Vol. 15 No. 2, pp. 86-92.

Ndekugri, I.E. and McCaffer, R. (1988), "Management information flow in construction companies", *Construction Management and Economics*, Vol. 6, pp. 273-94.

O'Brien, W.J., Fischer, M.A. and Jucker, J.V. (1995), "An economic view of project coordination", *Construction Management and Economics*, Vol. 13, pp. 393-400.

Pietroforte, R. (1997), "Communication and governance in the building process", *Construction Management and Economics*, Vol. 15, pp. 71-82.

Rezgui, Y. and Cooper, G. (1998), "A proposed open infrastructure for construction project document sharing", *Electronic Journal of Information Technology*, Vol. 3, pp. 11-24.

Rezgui, Y. and Debras, P. (1995), "An integrated approach for a model based document production and management", http://itcon.fagg.uni-lj.si/itcon/1995/1/, pp. 1-24.

Saad, I.M.H. and Hancher, D.E. (1998), "Multimedia for construction project management: project navigator", *Journal of Construction Engineering and Management*, Vol. 124 No. 1, pp. 82-9.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY.

Saaty, T.L. (1990), "How to make a decision: the analytic hierarchy process", *European*

Journal of Operational Research, Vol. 48, pp. 9-26.
Saaty, T.L. (1994), "How to make a decision: the analytic hierarchy process", *Interfaces*, Vol. 24 No. 6, pp. 19-43.
Sarshar, M., Aouad, G. and Brandon, P. (1994), "Improving project organisation through strategic planning of information", *The International Journal of Construction Information Technology*, Vol. 2 No. 3, pp. 77-94.
Shapira, A. and Retik, A. (1996). "Computer-integrated construction management: a case for octree-based representation", *The International Journal of Construction Information Technology*, Vol. 4 No. 1, pp. 61-82.
Tah, J.H.M., Howes, R. and Iosifidis, P. (1998), "Information modelling and sharing in the co-cis project", *The International Journal of Construction Information Technology*, Vol. 6 No. 2, pp. 67-85.
Tan, R.R. and Lu, Y. (1993), "On the quality of construction engineering design projects: criteria and impacting factors", *International Journal of Quality & Reliability Management*, Vol. 12 No. 5, pp. 18-37.
Yang, J. and Lee, H. (1997), "An AHP decision model for facility location selection", *Facilities*, Vol. 15 No. 9/10, pp. 241-54.
Zamanian, M.K. and Pittman, J.H. (1999), "A software industry perspective on AEC information models for distributed collaboration", *Automation in Construction*, Vol. 8, pp. 237-48.

Appendix

Table AI
The structure of construction information

1.	Managerial information			
	1.1	Planning		
		1.1.1	Construction initialization	
		1.1.2	Initial planning	
	1.2	Design		
		1.2.1	Initial design planning (architectural and structural designs)	
			1.2.1.1	Preliminary work
			1.2.1.2	Final work
		1.2.2	Design evaluation	
		1.2.3	Quantity surveying (QS) (including resourcing)	
		1.2.4	QS evaluation	
		1.2.5	Documentation	
	1.3	Procurement		
		1.3.1	Tendering	
		1.3.2	Directing	
		1.3.3	Scheduling	
	1.4	Construction		
		1.4.1	General contractor	
			1.4.1.1	Site related activities
			1.4.1.2	Construction's operation information
			1.4.1.3	Subcontractors' information
			1.4.1.4	Suppliers' information
		1.4.2	Sub-contractors	
		1.4.3	Workers	
			1.4.3.1	Shortage of information
			1.4.3.2	Conditions of work
			1.4.3.3	Competence of workforce
		1.4.4	Management	
			1.4.4.1	Management attitude
			1.4.4.2	Management Policy
		1.4.5	Surveying duties	
	1.5	Commissioning		
2.	Technical information			
	2.1	Planning		
	2.2	Design		
		2.2.1	Layout (e.g. column location or shape)	
		2.2.2	Preliminary design (e.g. column width or loads)	
		2.2.3	Analysis (e.g. member forces)	
		2.2.4	Detailed design (e.g. reinforcement ratio or material strength)	
		2.2.5	Designing (e.g. number of bars or reinforcement size)	

(continued)

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Table AI

2.3	Procurement		
2.4	Construction		
	2.4.1	Periodic valuations	
	2.4.2	Site production planning	
	2.4.3	On site production	
		2.4.3.1	Surroundings
		2.4.3.2	Usable work area
		2.4.3.3	Organization on site
	2.4.4	Constructability	
		2.4.4.1	Design issues
		2.4.4.2	Unavailability of information
		2.4.4.3	Errors and omissions
		2.4.4.4	Poor workmanship
		2.4.4.5	Sub-standard materials
	2.4.5	Plant	
		2.4.5.1	Delay problems
		2.4.5.2	Operator
		2.4.5.3	Appropriateness of chosen plant
		2.4.5.4	Theft and vandalism
		2.4.5.5	Insufficient space for plan operation
2.5	Commissioning		