Preventing Coordination Problems during the Design Stage of Projects

Essam Zaneldin

Department of Civil and Environmental Engineering, United Arab Emirates University, Al Ain, United Arab Emirates
Email: essamz@uaeu.ac.ae

***Abstract*— *The design stage of construction projects is considered one of the most fragmented stages in the life cycle of a project since it involves many participants and several geographic locations. Considering the giant size of the construction industry in the United Arab Emirates and the complexity of construction projects, it is hardly surprising that there are also coordination problems during the design process. Coordination problems, normally seen in the contract documents of almost every project, are direct results of the ongoing growth in the construction industry in the country. Decisions during the design stage have an extensive impact on all succeeding stages. Producing a quality design is highly dependent upon effective coordination among the diverse teams in the process. As a step towards effective design coordination, this paper investigates the manner by which expert designers prevent mistakes, detect mismatches, and communicate changes during the design stage. A questionnaire survey was conducted among design firms in the United Arab Emirates to collect information about the current coordination practice used during the design stage. Causes and frequency of coordination problems along with recommendations on solutions to these problems have been presented and areas of potential improvement have been identified. Based on the results of the survey, the study then suggested a coordination management scheme that can be used as a general guide to improve coordination during the design stage. Common interrelationships within the design development have also been explicated.*

***Keywords*— Coordination Problems, Design Process, Management, Quality Design, Questionnaire Survey.**

I. INTRODUCTION

Infrastructure development in the United Arab Emirates (UAE) at federal and local levels has been phenomenal in view of the relatively short period since the country's establishment. Modern cities have risen from the barren desert, connected by a vast network of first-class roads and linked to the outside world by modern airports and ports. Houses, schools, hospitals, shopping centers, telecommunications, electricity and water, luxury hotels and recreational facilities have all been provided for the people in a remarkably short space of time. The government of the UAE is constructing new infrastructure projects, office buildings, and residential accommodations. In view of the above, the construction industry is considered the UAE's largest single industry. Yet, it is also the most fragmented. Unlike the manufacturing industries, the construction pie is shared by many contractors and sub-contractors. Considering the giant size of the industry and the complexity of construction projects, it is hardly surprising that there are also coordination problems during the design process. Coordination problems, normally seen in the contract documents of almost every project, are direct results of the ongoing growth in the construction industry in the country and in Dubai and Abu Dhabi Emirates in particular. Bad coordination during the design process results in bad-quality tender documents.

Construction projects are becoming much more complex and difficult to manage. One complexity is the reciprocal interdependencies between different stakeholders, including those who are involved during the design stage [1, 2]. Considering this complexity, the quality of design has, undoubtedly, an extensive impact on all subsequent stages of a project's life cycle. Producing a quality design is highly dependent upon effective coordination among many teams, including architectural, structural, electrical, and mechanical. At present, however, coordination relies primarily on manual methods of crosschecking and frequent exchange of drawings and documents [3]. Such practice has thus been characterized as slow, costly, and ineffective [3-5]. In addition, most studies have confirmed the positive relationships between improved coordination and saving in project costs and time, as well as better safety and quality performance [6-10]. Currently, design offices are suffering from the lack of coordination among the different documents and the absence of effective guidelines and mechanism to solve such a serious and complicated problem. Examples of design coordination problems include contradictions, mismatches, errors, and discrepancies in drawings. This results in problems during constructions where late changes may be needed to correct coordination errors and mismatches. As illustrated in Fig. 1, coordination problems which may lead to changes during design and/or construction become very expensive and will have the greatest cost impact if implemented late during the construction stage of a project [11].

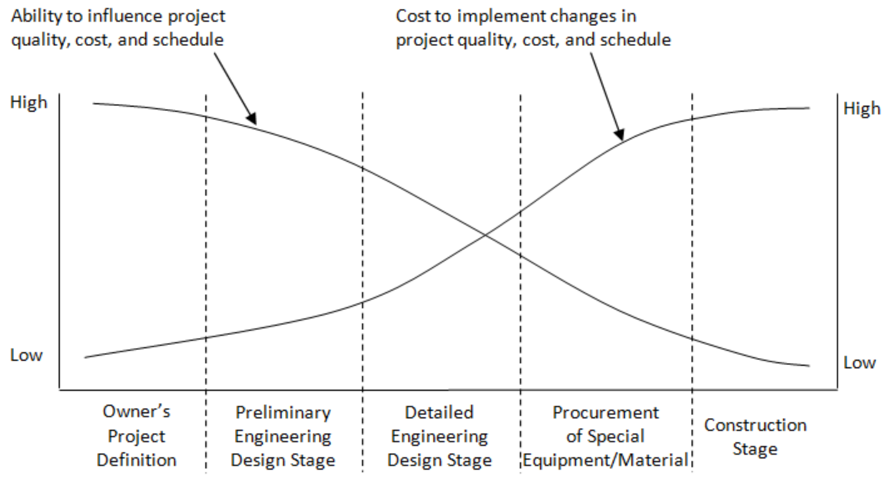
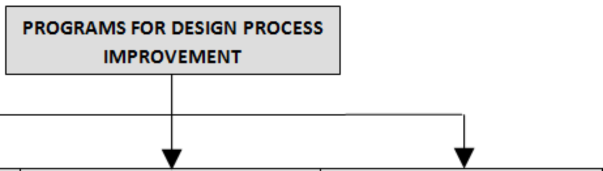


FIG. 1. EFFECT OF IMPLEMENTING CHANGES LATE DURING THE CONSTRUCTION STAGE OF A PROJECT [11].

The complex nature of the design process, in addition to the lack of a systematic approach to maintain quality, has contributed to the development of research in diverse areas related to design-process improvement. Constructability and value engineering, among other efforts, are three programs currently gaining wide acceptability in construction [12-14, 9]. A comparison among these design-process improvement programs is presented in Fig. 2. An interesting advancement is the developments made in Building Information Modeling (BIM) which suggest that not only is it useful for geometric modeling of buildings but also that it can assist in the management and coordination of construction projects. The next section discusses the developments made BIM and its benefits and possible drawbacks. A common characteristic among these programs is their focus on the interaction between design, as a single product, and other phases of a project's life cycle, particularly the construction phase. This, however, seems to place less emphasis on the multidisciplinary nature of the design development process. Design coordination, therefore, is an independent effort deemed appropriate to address the design development process and account for its unique difficulties and challenges. In this sense, design coordination can be an important complementary task to all other design process improvement programs, thus responding to many of the barriers to their effective implementation [15].



	CONSTRUCTABILITY	VALUE ENGINEERING	OTHERS
Description	Defined as the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve overall project objectives [26] Focus on optimizing the construction process in terms of construction cost, schedule, safety, and quality.	Defined as a multidisciplinary, systematic, and proactive function that is targeted at the design itself. The objective is to develop an item or a facility that will yield the least life-cycle cost or provide the greatest value, while also meeting all functional, safety, quality, operability, maintainability, durability, and other criteria established for it (AACE 1992).	Computer-Integrated Construction (CIC) and Building Information Modeling (BIM). Integrated Data Modeling and Product Modeling. Documentation of Standards and Specifications.
References	[12, 27, 28]	[29, 30]	[4, 5, 31-34]

FIG. 2. AVAILABLE PROGRAMS FOR DESIGN-PROCESS IMPROVEMENT.

It is, therefore, important to highlight and identify the common problem areas in design coordination, which, if not addressed properly, can lead to poor build ability and constructability problems of building projects [12].

II. BUILDING INFORMATION MODELING

Increasing complexity of construction projects motivated the developments made in information and communication technology (ICT) at a very fast pace [1, 16]. During the last decade, a major shift in ICT for the construction industry has been the proliferation of Building Information Modelling (BIM) in industrial and academic circles as the new Computer Aided Design (CAD) paradigm [17]. BIM has been defined as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" [17]. As discussed by [1], BIM has been utilized on high profile large-scale projects. It has been used in several mega-size projects in the UAE. Anticipating benefits from the use of BIM in respect of reduced transaction costs and less opportunity for errors to be made, the public and private sectors in the USA are collaborating to promote BIM's use [1, 18]. BIM not only allows the geometrical modelling and the input of information but also project management (PM)-related tools and processes. It has a potential use for construction project managers in improving collaboration between stakeholders, reducing the time needed for documentation of the project and, hence, producing beneficial project outcomes.

Despite the above mentioned benefits, there is a view that the case for BIM is not totally proven, with the overall effectiveness of BIM utilization still not completely justified [1, 19]. Although the price of the most popular BIM software packages is similar to that of the common CAD software, the complexity associated with using BIM software and the initial costs are still substantial, especially during the design stage for small- to medium-size design firms.

In an effort to establish a structured approach for improving design coordination, this research has focused on investigating the current practice used in coordination by conducting a questionnaire survey among leading design firms in United Arab Emirates. Based on the survey findings, causes and frequency of design coordination-related problems along with recommendations on solutions to some of these problems has been presented. Accordingly, prevailing practice has been presented and common conflict areas identified along with some simple heuristic rules used by expert designers to circumvent such conflicts. A design-coordination management scheme has also been suggested and areas of potential improvement to the design process were discussed.

III. METHODOLOGY AND SCOPE OF THE STUDY

To achieve the objectives of this study, a questionnaire survey was designed and a total of 112 surveys were distributed to 49 design firms across the UAE. The sample selected represents a wide range of geographical locations and population sizes. A total of 74 responses were received from design firms located mainly in Dubai and Abu Dhabi emirates in the UAE.

The survey was used to collect information from design firms in the UAE in order to investigate coordination-related problems in the current design practice. The collected data was then analyzed and the causes of design coordination-related problems were determined. The frequency of each of these problems was determined using the weighted average and the importance index. Illustrations and charts using Excel software are then presented. Using the responses received from the questionnaire survey, a coordination scheme was suggested. This scheme will help in setting a general guide for design firms in UAE to follow or change according to their own environment.

IV. QUESTIONNAIRE SURVEY

A questionnaire survey was first designed considering input (through interviews) from a number of expert designers. The survey was handed or emailed to 49 design firms mainly in Dubai and Abu Dhabi emirates in the UAE who have participated in a wide variety of small- to large- size projects. The survey was distributed to 112 practitioners (more than one design engineer in the same firm). This helped in collecting a total of 74 responses representing a 66% response rate. The questionnaire was organized into three main sections: (i) information about the organization, (ii) team coordination, and (iii) coordination among multidisciplinary design teams.

The first section of the survey elicited general information about the participating firms, including specialty, services, average job size, number of employees, and a ranking of the most costly items in the firm's operation. Analysis of the responses received shows the profile of respondents as illustrated in Fig. 3. As shown in the figure, most of the responding participants are architects and structural engineers representing 64% of all respondents. The figure also shows that participating firms provide mainly design services and the majority have a number of employees over 50. Fig. 4 also shows sizes and types of projects of participating firms. As can be depicted from the figure, the participating firms can be categorized as medium- to large-sized firms engaged in a wide spectrum of project types and sizes.

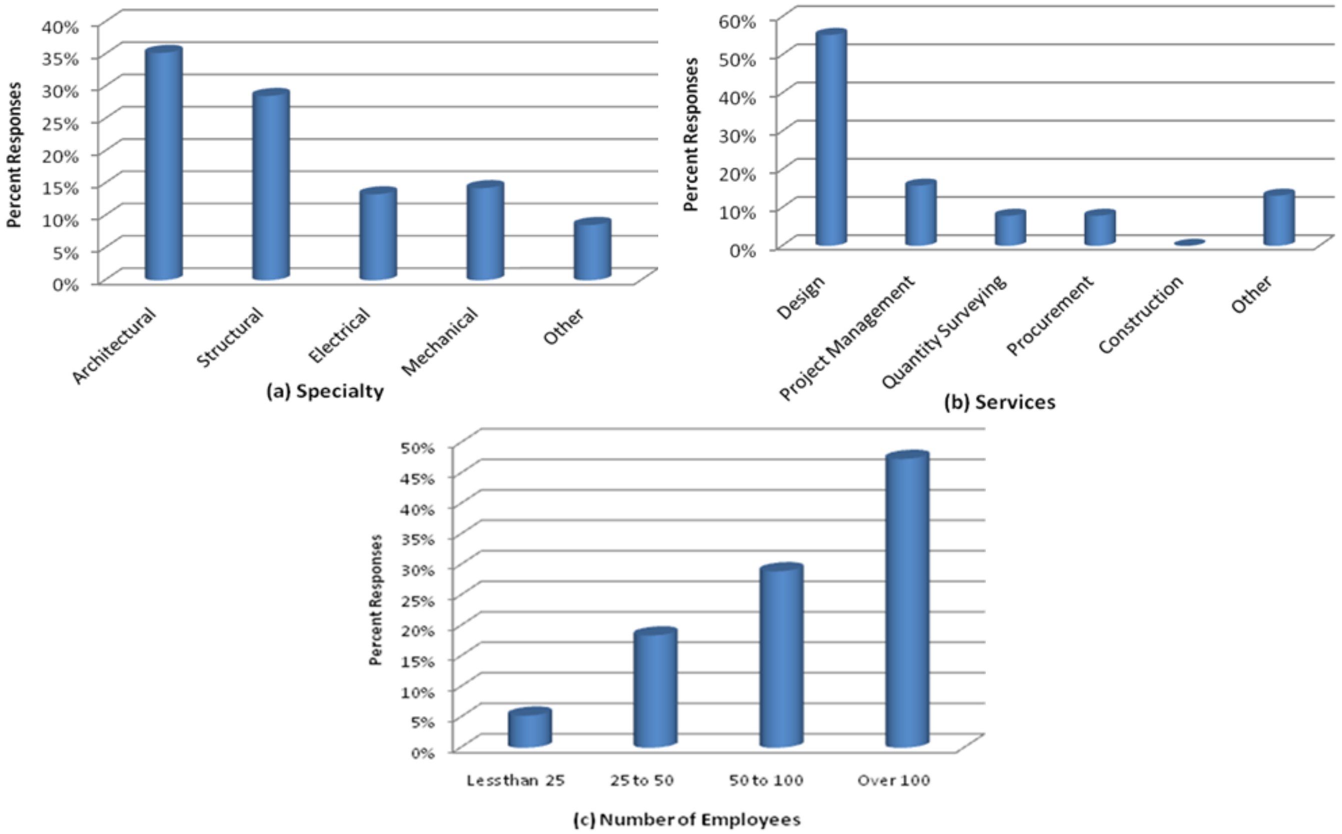


FIG. 3. PROFILE OF SURVEY RESPONDENTS

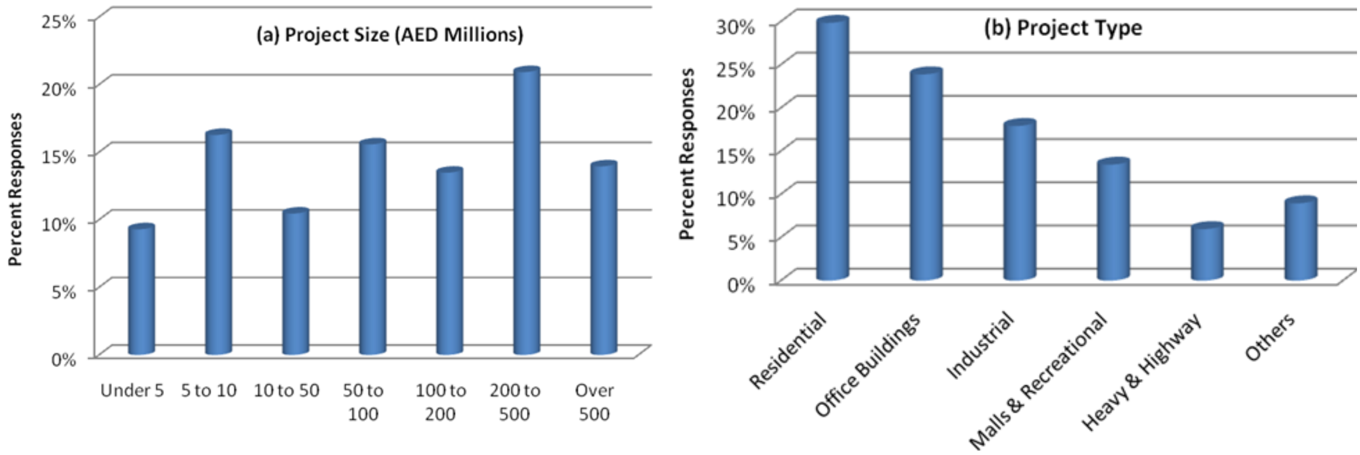


FIG. 4. SIZES AND TYPES OF PROJECTS OF PARTICIPATING FIRMS.

4.1 Team Coordination

The second section of the survey focused on the internal procedures used by the participating design firms to coordinate a particular design among team members. This section also elicited some of the team coordination problems encountered and designers' experience-based rules-of-thumb used to ensure consistency, circumvent errors, and detect problems. Surveyed practitioners were also asked to choose one of five possible options for the frequency of each team coordination problem. These five options are: never, rare, average, frequent, and very frequent. This will help in identifying how frequent each team coordination-problem happens according to the opinion of the surveyed practitioners.

From the responses received, the size and formation of a design team, as expected, were reported as job-size dependent. A typical team consists of 2 to 6 designers, 2 to 7 draftsmen, and a team leader. The average time a team takes to produce a preliminary design is 32 days (ranging from 20 to 45 days, depending on job size); and the average time taken to produce a detailed design is 130 days (ranging from 60 to 240 days). The tools used by the participating firms are primarily manual design and computer-aided drafting and design (CADD) or computer-aided drafting (CAD). Interestingly, only one firm was found to use the "Building Information Modeling (BIM)" software for detecting conflicts. The BIM is object-oriented representation of the facility that generates information that can be used to make decisions, detect conflicts, and improve the process of delivering the facility [20].

In general, coordination among team members is maintained through meetings when problems arise and consultations with team leaders. Common situations that promote inconsistencies in design and drawings within a team are compiled in Table 1, along with the preventive measures suggested by the respondents. The reasons behind these problems, as can be deduced from Table 1, are basically lack of administration of changes, errors caused by inefficient office procedures, and, to a limited extent, external factors. Also, simple tips and rules-of-thumb provided by respondents for preventing errors and better design coordination are presented in Table 2. Such tips can be used as helpful guidelines for organizing internal office procedures to ensure quality design and drawings.

TABLE 1
EXAMPLES OF TEAM COORDINATION PROBLEMS

Problem	Solution
Designers leaving project	Proper documentation of design
• Client is vague	• Ensure full understanding
• Designer is delaying the draftsmen	• Schedule the work and provide deadlines
• Information not distributed	• Ask, do not wait for others to tell you
• Vague directives	• Be direct: "Thomas to send information to ..."
• Last minute client changes	• Additional cycle of checking
• Changes come too quickly	• Must get sufficient time
• Drafting team omitted some important details	• Nominate one draftsman to be responsible for that matter
• Tight budgets	• Reduce complexity of design and reduce work hours
• Numerous changes	• Better coordination
• Omissions	• Thorough analysis

TABLE 2
EXPERT RULES-OF-THUMB FOR TEAM COORDINATION

Rule-of-Thumb or Tip	Reason
• Show dimensions once (either on plan or cross section)	• Change only once
• Establish early where to have bracing	• Design for lateral loads
• Simple hand calculations for the main forces	• Avoids big mistakes
• Standardize the user-defined variable names	• Prevents loss of information
• Try to have staff with field experience	• Find locations where things do not work
• Weekly interface meeting	• To discuss clashes and problems
• Communicate changes in writing and follow up with a meeting	• Ensure all members are working with the same information
• Trace the load path for structural loads	• This often finds a flow in design logic
• Look for architects' details that do not work	• Looking for disparity and big errors
• Level all general gridline dimensions and levels on architectural drawings and off structural, mechanical, and electrical drawings	• This minimize the change of conflicting information if only one dimension is updated
• Check similar structural members	• Looking for disparity and big errors
• Use the design and drafting checklists	• Looking for disparity and big errors
• Catalog and use typical details	• Consistency among projects
• Try to use the same team members	• Familiar and cooperative team
• Produce each drawing for a single scale	• Facilities implementations of changes
• Fully understand the limitations of your application software	• Prevents large mistakes
• Have master specifications with notes and highlight locations of frequent changes	• Aids in not forgetting clauses and avoids inconsistencies
• Cross check critical structural members	• Avoid serious errors

4.2 Coordination Among Multidisciplinary Design Teams

The third section of the survey elicited the participants' practice in coordinating a design among the different disciplines involved in a project. It also elicited some of the multi-team coordination problems frequently encountered and designers' rules-of-thumb used to ensure consistency and proper exchange of information among teams. Firms were also asked to choose one of five possible options for the frequency of each multi-team coordination problem. These five options are: never, rare, average, frequent, and very frequent.

Respondents provided information regarding their methods of (i) disseminating project information and (ii) administering design changes as two important aspects of multidisciplinary design coordination. On the one hand, disseminating design information among teams is primarily done through regular weekly or biweekly meetings. Respondents, however, highly emphasized the importance of starting these meetings early enough in the project, coupled with information seminars to communicate project objectives, ensure full understanding, and establish an effective coordination scheme. Design information and drawings are exchanged, according to the survey, mostly (60%) using paper rather than computer files (40%). Among the disadvantages of using paper, as replied by respondents, are printing time, cost, the time needed to locate information, and "killing too many trees." While computer files were perceived as less costly and more easily communicated, issues of their acceptance as official documents were raised, since they can be changed and it is sometimes cumbersome to keep track of their multiple versions.

Design changes, on the other hand, are documented by the respondents in memos and "change notices" that are carefully filed. In this regard, some firms follow the standard specifications for quality assurance and quality control, such as the British Standards. Among the first things to be checked by respondents when receiving a design change is its impact on design assumptions, the scope and area of change, approval by management, clarity of information, and budgetary implications. Examples of poor multidisciplinary design coordination are compiled in Table 3 along with the preventive measures suggested by the respondents. Also, some of their tips and rules-of-thumb used for preventing errors and better coordinating design are presented in Table 4.

TABLE 3
EXAMPLES OF MULTI-TEAM COORDINATION PROBLEMS

Problem	Solution
• Delay in obtaining information	• Regular meetings, phone calls, and deadlines
• Conflict	• Know what other teams want and how they work
• Late delivery of a piece of equipment due to mechanical team or not being informed of a change in construction method	• Full distribution of all the information
• The flow of information from the owner/contractor to the design team through different people causes misunderstandings	• Single point of contact
• Many changes in a short time period; not everyone in the team gets informed	• Cross-check that each individual gets all the information on the changes
• There will be, at times, all sorts of problems	• Solution is time, communication, and afterthought
• Inadequate structural headroom or design load for mechanical or electrical equipment	• Earlier start by mechanical and electrical teams and dialogue from all involved
• Mechanical opening required through a structural member	• Earlier start by mechanical and structural teams and dialogue from all involved

TABLE 4
EXPERT RULES-OF-THUMB FOR MULTI-TEAM COORDINATION

Rule-of-thumb or tip	Reason
• Maintain unofficial contact with other teams	• Find out about upcoming changes or problems
• Use a single set of drawings for review by all teams with comments color coded	• Have comments on one set of drawings, identifying who has checked what
• Estimate what answer you expect from other teams as you design	• Provides useful experience in checking designs
• Use a third party checker	• New look at work, independent viewpoint, more likely to notice missing information
• Try to eliminate complex design details	• Easy to communicate
• Establish a specific procedure to handle different design changes	• Standardize and simplify the implementation of changes
• Communication	• Silence is, among other things, the reason for many problems
• Check important (critical) areas, give priority	• Not everything has the same importance
• Check a few columns and beams particularly critical ones	• Gives benchmark for comparison and avoids serious errors
• Ask questions and remain open to answer questions from other teams	• Communication is of utmost importance on multi-team jobs
• Distribute the information consistently to all the teams, whether or not it seems necessary	• There may be impacts, which at the time of distribution, one may not be able to appreciate
• When necessary, press other teams to complete their work to answer your team's needs	• All teams work together to achieve quality design

4.3 A Suggested Coordination Scheme

The last part of section 3 of the survey requested the participants to identify important milestones throughout their design at which they need to send or receive information to and from other teams. Based on the responses received, the involvement of different design participants during the various design stages is presented in Fig. 5 and a coordination management scheme has been compiled in Table 5 showing, at different design stages, the information to be communicated and the purpose for which it is going to be used. In harmony with this scheme, common interrelationships among the participants throughout the design development process were schematically represented in Fig. 6.

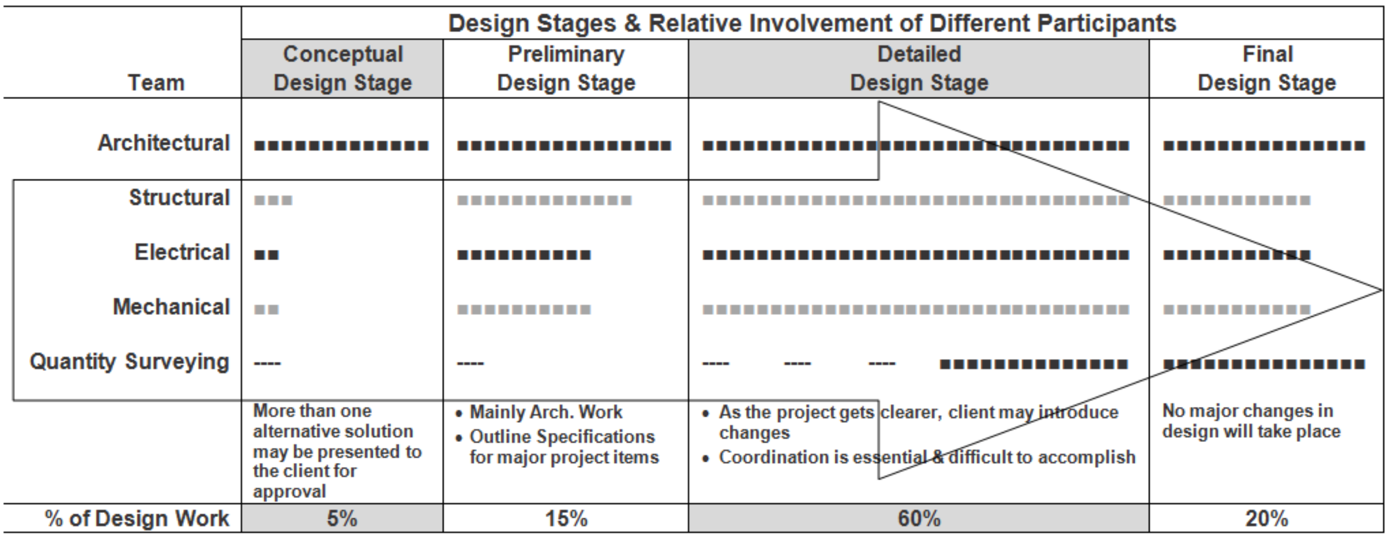


FIG. 5. INVOLVEMENT OF PARTICIPANTS DURING THE DIFFERENT DESIGN STAGES

The level of involvement of each team is presented in the figure along with the flow of the various design documents produced. This schematic figure can offer several benefits. It can be used to identify the parties to be communicated when a team introduces a certain change. Also, the relationships shown in the figure can be represented in a generic manner through semantic networks, expert system rules, and object-oriented formulations. Such representation enables the development of an automated procedure for administering design changes, which is a future extension to the present study.

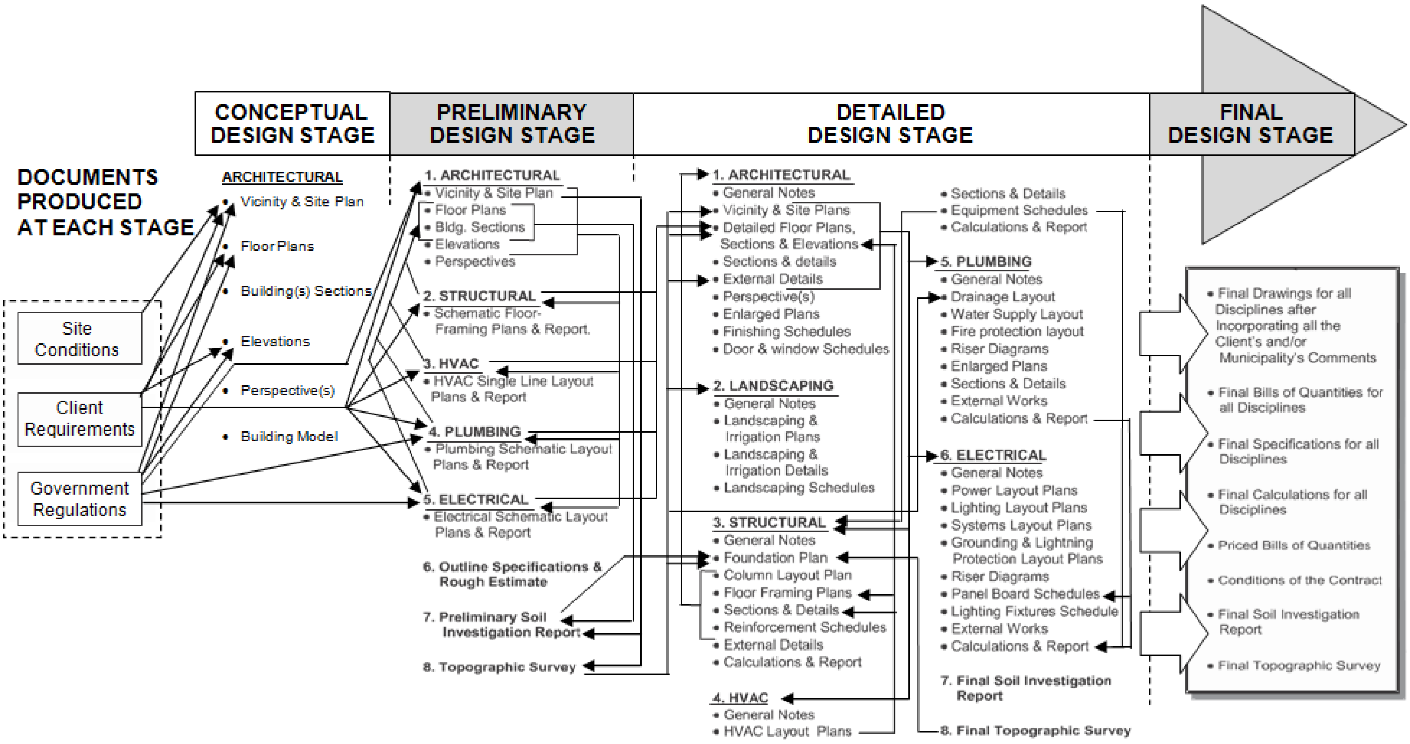


FIG. 6. INTERRELATIONSHIPS IN DESIGN DEVELOPMENT

The suggested coordination scheme of Table 5 sets a general guide for design firms to follow or change according to their own environment. In setting a similar scheme, input from different participants has to be encouraged, including suppliers and other third party subcontractors. Also, other factors could be considered such as design fast-tracking and contract requirements. Some respondents, for example, have indicated the possibility of starting foundation design after the 5–10% stage. This indicates the need to finalize the foundation package early enough to start construction as early as possible. In normal situations, however, foundation design is done once details of the superstructure have been finalized and accurate loads calculated.

4.4 Frequency of Design Coordination-Related Problems

As mentioned previously, to provide a realistic idea about the frequency of each type of design coordination-related problem, design practitioners were asked to choose one of five possible options for the frequency of each coordination problem. A weight in a scale from 0 to 4 was given for each of the five frequencies with a weight of 0 for ‘‘never, 1 for ‘‘rare’’, 2 for ‘‘average’’, 3 for ‘‘frequent’’ and 4 for ‘‘very frequent’’. No weight was given when no response was provided. The frequencies for each team and multi-team coordination problems are listed in Table 6 and Table 7, respectively.

Responses for the “information not distributed” team coordination problem shown in Table 6, for example, indicated that 2 design firms responded as “never”, 7 responded as “rare”, 9 responded as “average”, 33 responded as “frequent”, and 23 responded as “very frequent”. Data of Table 6 and Table 7 were analyzed and a weighted average was calculated for each coordination problem as follows: Weighted Average = $\sum (W_i \text{ X } X_i)/N$, where W_i is the weight assigned to the i^{th} option; X_i is the number of respondents who selected the i^{th} option; and N is the total number of respondents (74 in this study).

TABLE 5
FLOW OF INFORMATION FROM AND TO DIFFERENT DESIGN PARTIES

Design Stage	Information Flow	Type of Information	Use of information
0-5%	- Architect to owner	- Feasible conceptual design	- Owner to decide on best alternative(s)
5-10%	- Architect to all disciplines	- Size of project & conceptual design; type of construction (concrete, steel,…); client requirements; and project-specific requirements	- Assign resources; start preliminary studies and schematic design; prepare outline specifications and rough estimate; and prepare design criteria
10-15%	- Architect to surveying company	- Site plan	- Start topographic survey on site
	- Architect to soil investigation company	- Site plane, floor plans, and building sections	- Start soil investigation work on site
	- Mechanical to architect	- Location of shafts and the estimate of duct sizes	- Locate shafts on floor plans and decide on floor heights
	- Structural to architect	- Estimated beams sizes; and locations of columns and shear walls	- Decide on floor heights and locate columns and shear walls on floor plans
15-20%	- Architect to all disciplines	- Floor heights and preliminary building dimensions	- Prepare for detailed design
	- Surveying company to the architectural, structural, and mechanical disciplines	- Topographic survey drawings	- Identify building and footing levels, site grading, and site drainage
	- Soil investigation company to structural	- Preliminary soil investigation report	- Investigate feasible foundation types
20-40%	- Architect to all disciplines	- Completed preliminary architectural drawings	- Start detailed design
	- Mechanical to electrical	- Power requirements for mechanical equipment	- Design power supply
	- Mechanical to structural	- Equipment locations, loads, and openings in slabs	- Design slabs, beams, columns, and footings
40-60%	- Mechanical to architect	- Final mechanical duct size, shafts locations, and shafts dimensions	- Finalize floor heights and continue on the architectural plans, sections, and details
	- Mechanical to structural	- Final mechanical duct size, shafts locations, and shafts dimensions	- Finalize beam size and locations of openings
	- Structural to architect	- Final beam depth and column dimensions; and final column and shear wall locations	- Finalize floor heights and continue on the architectural plans, sections, and details
	- Electrical to architect	- Final electrical room dimensions	- Continue on the plans, sections, and details
	- Soil investigation company to structural	- Final soil investigation report	- Finalize foundation design
60-80%	- Architect to all disciplines	- Revised architectural drawings with external works including any changes and (or) modifications	- Finalize plans, sections, and details; and start quantity surveying and specifications
80-100%	- Architect to all disciplines	- Final architectural drawings including all the details and any changes or modifications	- Finalize drawings; finalize bill of quantities (BOQs) and priced BOQs; finalize specifications; and prepare conditions of the contract

TABLE 6
FREQUENCY OF EACH TEAM COORDINATION PROBLEM

Problem	No Response	Never	Rare	Average	Frequent	Very Frequent
• Designers leaving project	1	9	21	27	11	5
• Client is vague	7	4	6	11	22	24
• Designer is delaying the draftsmen	2	3	6	17	25	21
• Information not distributed	0	2	7	9	33	23
• Vague directives	1	9	24	15	17	8
• Last minute client changes	3	1	3	14	32	21
• Changes come too quickly	0	5	6	19	27	17
• Drafting team omitted some important details	0	3	6	17	27	21
• Tight budgets	7	8	11	26	19	3
• Numerous changes	0	7	9	27	21	10
• Omissions	0	8	11	25	19	11

TABLE 7
FREQUENCY OF EACH MULTI-TEAM COORDINATION PROBLEM

Problem	No Response	Never	Rare	Average	Frequent	Very Frequent
• Delay in obtaining information	0	4	9	14	29	18
• Conflict	3	8	35	19	7	2
• Late delivery of a piece of equipment due to mechanical team or not being informed of a change in construction method	4	7	18	22	14	9
• The flow of information from the owner/contractor to the design team through different people causes misunderstandings	0	9	15	11	22	17
• Many changes in a short time period; not everyone in the team gets informed	1	6	16	12	21	18
• There will be, at times, all sorts of problems	0	27	37	7	2	1
• Inadequate structural headroom or design load for mechanical or electrical equipment	0	5	7	18	28	16
• Mechanical opening required through a structural member	0	4	11	17	27	15

To better understand the importance of each coordination problems, an importance index percentage was then calculated as follows: Importance Index = Weighted Average times (100/4). The importance index values and ranking for each team and multi-team coordination problem are shown in Table 8 and Table 9, respectively. For example, the weighted average for the "information not distributed" team coordination problem = (0 X 2 + 1 X 7 + 2 X 9 + 3 X 33 + 4 X 23)/74 = 2.92. The importance index for this coordination problem = (2.92 X 100)/4 = 73%. The results of this analysis indicate that "information not distributed" team coordination problem is the most frequent coordination problem. This team coordination problem was ranked first with an importance index of 73%. "Last minute client changes" team coordination problem was ranked second with an importance index of 71.3% while "designers leaving project" team coordination problem was ranked last with an importance index of 42.20%. Similarly, the "delay in obtaining information" multi-team coordination problem was ranked first with an importance index of 66.2% while the "there will be, at times, all sorts of problems" multi-team coordination problem was ranked last with an importance index of 20.6%.

TABLE 8
RANKING OF EACH TEAM COORDINATION PROBLEM BASED ON FREQUENCIES

Problem	Importance Index (%)	Rank
• Information not distributed	73.0	1
• Last minute client changes	71.3	2
• Drafting team omitted some important details	69.3	3
• Designer is delaying the draftsmen	67.2	4
• Changes come too quickly	65.2	5
• Client is vague	64.2	6
• Numerous changes	56.1	7
• Omissions	54.7	8
• Vague directives	46.3	9
• Tight budgets	44.6	10
• Designers leaving project	43.2	11

TABLE 9
RANKING OF EACH MULTI-TEAM COORDINATION PROBLEM BASED ON FREQUENCIES

Problem	Importance Index (%)	Rank
• Delay in obtaining information	66.2	1
• Inadequate structural headroom or design load for mechanical or electrical equipment	64.5	2
• Mechanical opening required through a structural member	62.8	3
• Many changes in a short time period; not everyone in the team gets informed	59.1	4
• The flow of information from the owner/contractor to the design team through different people causes misunderstandings	57.8	5
• Late delivery of a piece of equipment due to mechanical team or not being informed of a change in construction method	47.3	6
• Conflict	34.5	7
• There will be, at times, all sorts of problems	20.6	8

V. AREAS OF POTENTIAL IMPROVEMENT

A In addition to the information presented earlier, survey respondents provided several interesting comments and criticisms to current practice that can give insight into future research directions. One of the important issues raised is the problem associated with the large amount of paper work involved in the design process. Some of the disadvantages of using paper as the main communication media have been outlined earlier. A major obstacle to the efficient use of electronic files for communicating design information, despite recent advances, is the lack of appropriate filing systems for organizing the multitude of drawing files with their several updates and other related documents concerning specifications, changes, and other information. This is in addition to the problems of security, confidentiality, and acceptability as an official medium. While there is a noticeable shift from paper-based procedures, as observed from the survey results, survey respondents have reported it as insufficient and called for more research in paperless office procedures and the use of new substitute technology for better communication.

Among the recent computer advances that can undoubtedly have a major impact on design coordination is the Internet. The Internet has emerged as a revolutionary low cost computerized tool for worldwide communications, effective marketing, and procurement of services and (or) information. The Internet is particularly useful to support information-dependent processes such as multidisciplinary designs that require close cooperation among a group of diverse and possibly remote experts. Also, Internet can provide several benefits to the design process, including a possible reduction in travel cost, which was found from the responses to be the fourth-most costly item in office operations after salaries, rent, and hardware and software. Though the construction industry has been slow to adopt almost all new technologies, the Internet is, by far, the fastest growing computer technology that the construction industry has to catch up with. In the near future, the use of such technology will not only increase productivity and work coordination but will also mean life or death of an organization. Ultimately, with the introduction of new solutions for security and confidentiality issues, the Internet technology can offer a design office much more than the telephone and facsimile technologies are providing today.

With the powerful Internet ability of being easily programmable, many industries, including construction, are recently showing increasing interest in adopting it. In construction, several direct applications have demonstrated the usefulness of Internet-based bidding, communicating site control data [21], and Internet publishing of project-specific design data [22]. A variety of Internet-based software and hardware systems are being produced at an astonishingly fast pace. These systems cover a wide range of tools for individuals, small businesses, and large enterprises who can tie their local or wide-area networks to the Internet, forming Intranets. With little cost involved, tools such as Internet telephones, video conferencing, remote control, Internet meeting, white-board discussions, and document conferencing may be used, individually or combined, to provide custom solutions for design coordination and site to head-office communication as well. In addition to remote communication, Internet abilities to trace and document users' actions have direct application in the management of the many anticipated changes during design. Using the proper tools, a network administrator can monitor users' access times, the commands they use, and the changes they make. To facilitate that within a cooperative environment, several document and contact management systems and collaboration software have recently become available (e.g., Lotus Notes and Microsoft Exchange Server). These systems provide general-purpose group scheduling, database management, and file sharing in addition to their Internet capabilities.

The success of a design coordination scheme is undoubtedly dependent upon effective management of not only the available resources but also the flow of the large amount of information involved. Since the suggested coordination scheme in Table 5 and Fig. 6 described a general flow of design information, a more thorough analysis of the design process may become necessary. This includes the use of data-flow diagrams (e.g., [23]) to examine the flow of the large amount of design data among the diverse participants in the process. Also, with the use of recent computer programs for process-analysis and project portfolio management (e.g., [24]), simple flow charting and simulation can be used to model the design process, identify bottleneck points, and monitor the production of resources at each step. The benefits of such analysis are ample, including optimum selection of team size, refinement of communication milestones, estimation of realistic design time and cost, and the evaluation of the impact of changes in the process. These tools, as such, not only provide a better understanding of the design process, but also can be used to compare the effectiveness of traditional design procedures versus modified procedures based on quality standards such as ISO 9001. This will emphasize the benefits of adhering to such standards and enable design offices to arrange their resources in a manner that meets quality requirements.

With CAD and BIM software becoming basic tools in design offices and increasingly popular, files proliferate until projects contain hundreds or thousands of original, secondary, and backup drawings [3]. Engineers spend too much time finding information that should be easily accessed and files become extremely difficult to organize, let alone the associated paper prints, memos, faxes, and reports. As reported by many researchers [25] and depicted from the findings of the present survey, this has been one of the biggest challenges to the operation of the design office. An essential component of a successful design coordination program, therefore, is a document-management solution that is accurate, fast, and reliable. The perceived benefits of this solution include the possible recognition of secure electronic files as legal documents, which facilitates a smooth and effective shift from paper-based procedures.

Based on this discussion, several extensions to the present study are currently being carried out to provide an automated solution to design coordination. Developments are currently being made to form a comprehensive system for group scheduling, design-change administration, and file management. This includes the use of international standards, Internet-based group-scheduling tools such as Lotus Notes, and additional modules for system integration.

VI. CONCLUDING REMARKS

This study identified design coordination as an independent program that needs to be strengthened within design firms. As a step towards enhancing the design coordination process, a questionnaire survey was conducted among 49 design firms in the United Arab Emirates and 74 responses were received. The survey elicited current practice related to design coordination at the inter-team level and the interdisciplinary level as well. Based on the survey responses, design coordination-related problems were identified along with the causes and frequency of these problems. Suggested solutions were presented along with expert rules-of-thumb used by practitioners to prevent mistakes, detect mismatches, and effectively communicate design changes. This study can be used to identify several common coordination-related problem areas in the design process in UAE with an effective and low cost manner. One of the common problem areas is the "information not distributed" team coordination problem which, according to this study, was the most frequent problem and needs special consideration. “Last minute client changes” problem came second and “designers leaving project” was ranked last. It can also be concluded that “delay in obtaining information” is the most frequent multi-team coordination problem while “there will be, at times, all sorts of problems” was ranked last, indicating that it is the least frequent multi-team coordination problem.

Based on the survey findings, four main areas of potential improvement to the multidisciplinary design process were identified for future research: 1) full use of Internet technology as a low cost tool for effective communication among remote experts; 2) the use of process analysis techniques to model the flow of design information, identify conflict areas, and resolve coordination problems; and 3) better organization and documentation of electronic filing systems that enable a practical and cost-effective shift from the prevailing paper-based procedures; and 4) the use of “Building Information Modeling (BIM)” software to simulate the construction of a project to improve coordination and detect conflicts. Perceived benefits are improved design consistency, increased productivity, cost savings, and better constructability of projects.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the College of Engineering at UAE University for the financial support of this research. The author also acknowledges the help of design firms in the UAE who participated in responding to the questionnaire survey. Without their great help and insightful input, this study would not have been possible.

REFERENCES

[1] D. Bryde, M. Broquetas, and J. Volm, “The project benefits of building information modelling (BIM),” International Journal of Project Management, vol. 31, pp. 971–980, 2013.
[2] R. Clough, G. Sears, and S. Sears, “Construction project management: a practical guide to field construction management,” Wiley, New Jersey, 2008.
[3] R. Mooney, “A call for quality in engineering business (and Computer Tools to Get us There): editorial,” ASCE Journal of Computing in Civil Engineering, vol. 9 (3), pp. 191–193, 1995.
[4] P. Teicholz and M. Fischer, “Strategy for computer integrated construction technology,” ASCE Journal of Construction Engineering and Management, vol. 120 (1), pp. 117–131, 1994.
[5] A. Dubois, and F. Parand, “COMBINE integrated data model,” Proceedings of the Chartered Institution of Building Services Engineers National Conference, pp. 96–108, 1993.
[6] A. Griffith and A. Sidwell, “Development of constructability concepts, principles and practices engineering,” Construction and Architectural Management, vol. 4 (4), pp. 295-310, 1997.
[7] V. Francis, V. Mehrtens, A. Sidwell, W. and McGeorge, “Constructability strategy for improved project performance,” Architectural Science Review, vol. 42, pp. 133-138, 1999.
[8] G. Jergeas and J. Put, “Benefits of constructability on construction projects,” Journal of Construction Engineering and Management, vol. 127 (4), pp. 281-290, 2001.
[9] S. Low and B. Abeyegoonasekera, “Integrating buildability in ISO 9000 quality management systems: case study of a condominium project,” Building and Environment, vol. 36 (3), pp. 299-312, 2001.
[10] B. Trigunarsyah, “A review of current practice in constructability improvement: case studies on construction projects in Indonesia,” Construction Management and Economics, vol. 22 (6), pp. 567-580, 2004.
[11] G. Oberlender, “Project management for engineering and construction,” Third Edition, McGraw Hill, 2014.
[12] P. Lam, F. Wong, and A. Chan, “Contributions of designers to improving buildability and constructability,” Design Studies Journal, vol. 27 (4), pp. 457-479, 2006.
[13] Building and Construction Authority (BCA), “Code of practice on buildable design,” BCA, Singapore, 2004.
[14] D. Arditi, A. Elhassan, Y. and Toklu, “Constructability analysis in the design firm,” Journal of Construction Engineering and Management, vol. 128 (2), pp. 117-126, 2002.
[15] L. Aaron, “Constructability in skills and knowledge track workbook,” AACE International 40th Annual Meeting, the Association for the Advancement of Cost Engineering, Morgantown, W. Va., USA, 1996.
[16] L. Taxén and J. Lilliesköld, “Images as action instruments in complex projects,” International Journal of Project Management, vol. 26 (5), pp. 527–536, 2008.
[17] B. Succar, “Building information modelling framework: a research and delivery foundation for industry stakeholders,” Automation in Construction, vol. 18 (3), pp. 357–375, 2009.
[18] J. Underwood, U. Isikdag, “Emerging technologies for BIM 2.0,” Construction Innovation: Information, Process, Management, vol. 11 (3), pp. 252–258, 2011.
[19] Y. Jung, M. Joo, “Building information modelling (BIM) framework for practical implementation,” Automation in Construction, vol. 20 (2), pp. 126–133, 2010.
[20] AGC, “The contractors’ guide to BIM,” The Associated General Contractors of America, 2300 Wilson Blvd., Suite 400, Arlington, VA 22201, USA, 2009.

[21] P. Seesing, “Distributing project control database information on the World Wide Web,” Project Management Network Magazine, Project Management Institute, vol. X (10), pp. 22–26, 1996.

[22] J. Schriener and M. Phair, “Booming beget nailbiters,” ENR Magazine, vol. 237 (18), pp. 26–30, 1996.

[23] A. Abou-Zeid, J. Russell, A. Hanna, and S. Park, “Data flow model for communications between project participants in a highway bridge project,” Canadian Journal of Civil Engineering, vol. 22 (6), pp. 1224–1234, 1995.

[24] Sciforma PSNext, “User’s guide,” Sciforma Corporation, Suite 5, 985 University Avenue, Los Gatos, CA 95032, USA, 2016.

[25] M. Petko, “Documentation, documentation, documentation,” Project Management Network Magazine, Project Management Institute, vol. X (9), pp. 5–6, 1996.

[26] AACE, “Skills and knowledge of cost engineering,” 3rd Ed. AACE International, Morgantown, W. Va., USA, 1992.

[27] J. Russel, J. Gugel, and M. Radtke, “Comparative analysis of three constructability approaches,” ASCE Journal of Construction Engineering and Management, vol. 120 (1), pp. 180–195, 1994.

[28] N. Eldin, “Constructability improvement of project designs,” ASCE Journal of Construction Engineering and Management, vol. 114 (4), 631–640, 1988.

[29] A. Dell’Isola, “Every penny’s worth,” Civil Engineering Magazine, ASCE, vol. 61 (7), pp. 66–68, 1991.

[30] I. Basha and A. Gab-Allah, “Value engineering in Egyptian bridge construction,” ASCE Journal of Construction Engineering and Management, vol. 117 (3), 393–401, 1991.

[31] Y. Yamazaki, “Integrated design and construction planning system for computer integrated construction,” Journal of Automation in Construction, vol. 1, pp. 21–26, 1992.

[32] J. O’Connor and P. Caraway, “Need for specification format that accommodates engineered projects,” ASCE Journal of Construction Engineering and Management, vol. 119 (4), pp. 757–768, 1993.

[33] S. Evt, S. Khayyal, and V. Sanvido, “Representing building product information using hypermedia,” ASCE Journal of Computing in Civil Engineering, vol. 6 (1), pp. 3–18, 1992.

[34] A. Wright, S. Lockley, and T. Wiltshire, “Sharing data between application programs in building design: product models and object-oriented programming,” Building and Environment, Pergamon Press Ltd., vol. 27 (2), pp. 163–171, 1992.