Quantity Surveys from Shared CAD Object Models: A Development Strategy

by

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ABSTRACT

The current practices of information exchange between designers and contractors in the AEC industry are still primarily via paper drawings and specifications. This thesis reviews the way the industry generates quantity surveys for cost estimating purposes and deems them as inefficient. CAD object models with linked databases are proposed as a means for integrating information exchange and generating quantity surveys. They would be shared from designer to contractor, providing many benefits to each party as well as to the client. The proposal is for an industry wide basis, and would maintain the existing distribution of design and construction knowledge between designers and contractors. The thesis differentiates between quantity surveying and cost estimating, and argues that quantity surveying can be performed by knowledge-based systems.

The proposal recognizes a number of organizational and technological issues impeding the development of such a system, and suggests solutions to them. Three issues command the most attention. First, specific software, hardware and operation costs of the proposal must be further defined. Second, designers will reassume responsibility for indicating more detail information, and the computer will assume more of the general contractor's coordination responsibilities. Third, the creation of a General Library of all potential construction material objects and attributes is seen as the biggest challenge to the development because of the difficulty in organizing the effort to establish and ratify standards in the fragmented AEC industry. The promotion of project information standardization and electronic integration are put forth as good first steps towards the development of the proposed system. The thesis serves as a strategy for developing and promoting CAD object models that may be shared for quantity surveying and later other construction management purposes.

Thesis Supervisor: Dr. Jonathan Cherneff

Intelligent Engineering Systems Laboratory

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I would like to thank my employer, Dunn Construction Company, for affording me the opportunity to study at MIT. Dunn is worthy of tribute for having the long term vision to invest in its employees' continuing education.

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BIOGRAPHY

Mr. Edwards graduated from high school in Florence, Alabama where he worked summer jobs during college performing construction on industrial projects. He graduated Cum Laude from Vanderbilt University in Nashville, Tennessee, with a B.E. in Civil Engineering. He was a member of Tau Beta Pi and Chi Epsilon honorary fraternities. After graduation in May 1988, he began work as a Project Coordinator for Dunn Construction Company of Jackson, Mississippi and Birmingham, Alabama, and was later promoted to Project Manager. Before attending MIT he managed projects in three states, including the $32 million Civic Center Hotel in Birmingham. He concurrently performed quantity surveying and estimating on a wide range of projects.

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Chapter I. Introduction

The U.S. architecture-engineering-construction (AEC) industry is plagued by high fragmentation on an industry wide basis as well as on an individual project basis. The industry wide basis is characterized by the large number of AEC firms and the fact that none have a clear dominant position. This type of fragmentation reduces profit margins, explaining the low level of research and development in the industry, which in turn affects the quality of design and construction. Fragmentation on an individual project basis is characterized by the wide distribution of responsibilities among a number of firms during specific phases of a project, e.g., an architect relies on many consulting engineers during design; and a contractor coordinates all the specialty subcontractors during construction. The most noticeable example of project fragmentation is between phases, i.e., from design to construction, because the firms involved have different goals and are members of different contract teams. This thesis is about reducing project phase fragmentation, whose effects include low quality design and construction, poor communication, and adversarial relationships between the firms. Reducing fragmentation has been coined "integration." This thesis proposes to integrate project information electronically between designers and contractors via computer aided design (CAD) object models.

This thesis considers the majority of AEC work where separate firms perform design and construction, as opposed to the smaller volume of design-build work. Procurement of this type of construction is often called "plans and specs bidding" because contractors bid on drawings and specifications prepared by separate designers. The thesis is also applicable to the large portion of design-build projects where much of the construction work is bid and subcontracted to separate construction firms. Designers have implemented a number of electronic systems to assist them during design, like CAD, but the current practice of exchanging project information from designers to contractors is little different from over 100 years ago. Designers complete designs (now they usually use CAD), print them out on paper drawings and specifications, and hand them over to contractors. Contractors prepare and return bids, and later coordination drawings and schedules. They also use sophisticated systems to generate their data. Together this has been called "over the wall" communication because there is little ongoing dialogue and no linkage of information systems. The integration effort involves understanding the type and style of information both parties need, and finding methods to link information systems that will improve efficiency and reduce errors.

One area of information exchange that is especially inefficient and error prone is the development of the quantity survey, or takeoff, which is the first step to generating a cost estimate. Contractors are required to read the designers' drawings that are composed of graphic representations, and interpret what the designers intended to be built. This is a very tedious task because every material required to complete the design must be counted and measured to ensure cost accuracy. Errors occur in the measurement and calculation of the quantities that often financially cripple a contractor. Some errors, or rather misunderstandings, occur due to different interpretations of the drawings or specifications. Invariably contractors interpret differently from the designers' intent causing conflicts over contractual scopes of work, otherwise referred to as "change order wars." Contractors take the position that the drawings are either incomplete or not prepared in the standard representation, and designers take the position that the contractor does not know how to interpret the drawings properly.

Due to the high number of man-hours it takes to complete a takeoff, quantity surveying is prone to inefficiencies. Clearly inefficient is the fact that all bidding contractors (often five or more for each scope of work) duplicate the same costly effort. Computer hardware and software developers have created systems that improve the takeoff process, just as CAD systems have improved the design process. Information about a typical project is drafted into a CAD system by the designers, printed out onto paper drawings, and then keyed or digitized back into an estimating program by the contractor. This is a textbook example of "local islands of automation" [McKenney] that AEC industry commentators have described as "unCAD" [Howard et al.]. Recently a few estimating software developers have linked their systems with CAD systems and eliminated the need for paper drawings, but the takeoff procedure is still manual (on the display screen) and tedious. (See for example the MC^2®-AutoCAD® package [Management Computer Controls] and the Precision CAD Integrator® [Timberline]).

This thesis proposes that designers use 3D CAD object models to create designs and quantity surveys of the designs. CAD object models are different from common design representations (CAD or manually drafted) that are simply a series of points, lines, arcs, or shapes that require interpretation to provide meaning. CAD object models design with intelligent objects, i.e., users can define the points, lines, arcs, or shapes as parts of an object and add a description to the object. The objects can be electronically linked to a database management system (DBMS), that can list information, called attributes, about each object. The thesis proposes that such a database be used to create a complete and detailed quantity survey. The object model CAD system and linked database should create and maintain their data in a new standard fashion that can be recognized across the AEC industry. The thesis proposes that the CAD and database files be shared with bidding contractors who would each use the common quantity survey to generate their own estimates using proprietary methods.

The thesis refers collectively to the proposed object model CAD system and linked database as the System. The System is proposed to be developed for the open commercial market of designers and contractors, as opposed to large design-build firms who might have already developed their own proprietary systems that do not represent data in a universal fashion. Implementation of the proposal will serve a number of benefits and purposes, including eliminating the current problems of quantity surveying. It will also serve as the first step towards electronically integrating the design and construction processes. However, there are many difficult issues surrounding this proposal, otherwise it might already have been implemented. Designers do not want to accept responsibility for generating quantities; contractors all do their estimating differently; and initial costs may outnumber initial benefits. These are just are just a few examples of the issues involved. The largest issue is the development of a standard for representing each of the many thousands of building materials and that will be recognized across the industry. The thesis provides a strategy for overcoming these issues and convincing industry players to develop and use the proposed System. The proposal is based on maintaining the existing distribution of knowledge between designers and contractors so as to preserve productivity gains from specialization [Howard et al.].

The thesis is organized by first describing in Chapter II, *Rationale for Proposal*, the history of and problems associated with quantity surveying and cost budgeting in the U.S. The chapter proceeds to describe alternative methods of generating quantity surveys. Chapter III, *Benefits of Proposed Composite Information System*, outlines what contractors, designers, and clients stand to gain from the proposal. Chapter IV, *Problems and Issues of Proposal*, states the issues that impede the development and use of the proposed System. Chapter V, *Description of System Proposed*, relates the exchange of project information from designers to contractors, and describes the components of the System as well as their use. Chapter VI, *Responses to Problems and Issues*, suggests solutions for the issues raised in Chapter IV. Chapter VII, *Promotion, Development, and Implementation of Proposed System*, offers the further steps that need to be taken by the industry to move this thesis proposal forward. Chapter VIII, *Summary and Conclusions*, summarizes the net benefits of the proposed System in light of the issues.

Note: The terms designer, contractor and client are used throughout the thesis to represent the players in the typical constructed facility scenario. Designer refers collectively to architects, engineers, sub consultants, etc., who are responsible for working with the client to establish a design and later administer over the contractor. Contractor refers collectively to general contractors, subcontractors, fabricators, etc., who are responsible for constructing the design. Client refers to the project owner or beneficiary. No attempt is made to differentiate the many different types of contract situations (with the exception of design-build) because they do not affect the basic issue being studied, i.e., the exchange of project information from design to construction.

Chapter II. Rationale for Proposal

This chapter describes the rationale for proposing to integrate the flow of information from designers to contractors, specifically quantity survey information. The chapter provides a summary of the state of fragmentation and a history of project communication without integration. The basis of the rationale for the proposal is that the current method for generating budget estimates and quantity surveys in the U.S. is inefficient, and that there are better methods available.

A. Industry Fragmentation and Integration

The U.S. AEC industry is a textbook example of a fragmented industry, based on Porter's criteria [Porter] that will be indicated in italics. No design, contracting, or design-build firm has a *significant market share,* and hence cannot influence the industry outcome. There are a large number of firms competing, exemplified by the fact that the 400 largest contractors in 1992 ranked by Engineering News Record (ENR) completed only $74.9 billion, or a meager 31%, of the $239 billion U.S. nonresidential market [Krizan, MacAuley]. The $184 billion residential contracting market is even more fragmented with tens of thousands of contractors. Design firms are so numerous that ENR ranks the top 500 annually. The largest firm in the industry, Fluor Corporation, who performs design and construction, ranks only 252nd based on all U.S. firms' stock market value [*Business Week*, 1993]. All this is despite the fact that the construction industry (not including the booming markets for maintenance, renovation, and hazardous waste cleanup) maintains a substantial 7.9% of the gross national product [MacAuley].

Reasons for the fragmentation are the *low entry barriers* for the design industry, requiring only certification and little capital. Contracting firms have even *lower entry barriers* since relatively no certification is required, and firms can be started with minimal capital. No design or contracting firm has been able to institute definite *economies of scale* since the constructed project is rarely repeated identically. The fluctuating economy, changes in government spending policy, and the uncertain outcomes of the low-bid procurement method create *erratic sales fluctuations* that keep companies from adding capacity that otherwise might be used to gain market share. Although there are many different types, *buyers and their bargaining power* make it difficult to influence industry outcome. The largest buyer, the Federal Government, is, however, beginning to require a uniform integrated CAD standard through the NAVFAC CAD2 contract that a powerful player in a less fragmented industry might be able to institute on its own (like American Airlines did with their SABRE reservation system). In the 1980s NAVFAC chose to stand aside and let the industry shake out the many poor CAD developers, who themselves were in a fragmented stage [Fox]. A final reason for AEC fragmentation is the *diverse market needs.* AEC firms usually specialize in a subclassification within the broad market classifications of housing, general building, petroleum, transportation, power, water supply, hazardous waste, manufacturing, and sewer.

Fragmentation, although it creates competition and helps to keep project costs in check, generates considerable problems for the industry including reduced profitability for the firms. This forces the firms to maintain low overheads and invest essentially zero in research and development. The U.S. industry has primarily relied on academia to develop technologies, and has been slow to test and implement them. In comparison, the larger firms in Japan's less fragmented AEC industry regularly invest up to $100 million a year in R&D [MacAuley] and are considered to be leapfrogging U.S. firms in construction automation and information systems. Although CAD systems began to proliferate through the design side of the industry in the 80's, little information technology has been developed and adopted by the contracting side of the industry.

The second problem fragmentation has created is the lack of uniform standards for representing project information. By early this century a common graphical language printed on paper drawings emerged as a de facto standard for representing a portion of project information. The balance of project information is provided via written text in specifications, which by the 1950s came to be presented in a partially accepted de facto standard, the Construction Specification Institute (CSI) format. There is still today no standard for delineating what project information should be included in the drawings and what should be included in the specifications. However, the Construction Sciences Research Foundation has proposed the ConDoc® program as a standard to remedy this. The next section will belabor the problems of drawings and specifications. Efforts to create and transmit this information electronically have run into serious problems with file format standards. In the 1980's the government sponsored an initiative to standardize the graphic and geometric data through the Initial Graphic Exchange Specification (IGES), which was quickly bypassed by the leading CAD developers, who created more robust but proprietary file formats. The most recent government and industry attempt to standardize electronic data, Product Data Exchange using STEP (STandard for Exchange of Product data), or PDES, is not even supported by the leading CAD developers! What all this creates is a communication barrier between firms attempting to work on the same project but who operate a different CAD or information system. There is no dominant player in the AEC industry to take a lead in instituting industry wide standards, so the industry is forced to wait on the persistent, but slow, government.

The AEC industry has evolved over the years into a system of specialists. Architects and engineers separated from builders in the 19th century, and then into many specialties or sub-consultants. Builders also specialized by trade into contractors and subcontractors. Many will argue that this is the basis for the explosive productivity gains of the 1940s, 50s, and 60s [Cremeans], as firms concentrated on their core competencies. This split and specialization, however, cause vertical fragmentation (between project phases, e.g., design, construction, and operation) and horizontal fragmentation (between specialists, e.g., electrical and mechanical during construction). This has created the recent awareness in the popular press [Carroll (Autumn 1991); Argie; Stowe; Jordani; Ross; Chamberlain] and the academic press [Yau et al.; Howard et al.; English; Reinschmidt et al. (1989)] about the need to integrate the phases and specialties through database-driven CAD systems. However, the articles and papers are applicable to design and design-build firms, and neglect the fact that the most common procurement system in the U.S. selects a designer and contractor separately, making integration, much less electronic integration, difficult, to say the least. When asked about integration of project information, one industry leader jokingly countered "Haven't you given up on trying to integrate the construction process?" [Carroll 1993] implying that it is a difficult task.

Since designers commence the project information process, it is understandable that they select information systems to suit their own needs, and, unfortunately, these systems require contractors (and their subcontractors) to translate the information mentally and electronically. One of the problems with trying to integrate any part of the construction process is that nobody knows what information is valuable to the next party in the value chain. The next section describes the process contractors use to translate the designers' information mentally for their use and purpose, dubbed "interpretation."

B. Nature of Design and Interpretation

A project is conceived when a client recognizes a need for a facility or infrastructure. The client conveys its need to an architect or engineer (designer) via written or spoken requirements and requests, e.g., space for 200 students, 50 MW of power, a $5 million budget. The designer processes that information through a problem solving phase and develops a "conceptual design" to meet all the client's requirements. The conceptual design is originally developed in the designer's mind, and must be communicated to the client and other members of the design team. For this reason, a graphical language via sketches is used to represent the conceptual design. The conceptual design is then refined into a more detailed set of "working drawings" in order that contractors can determine how to build the concept.

Cherneff [Cherneff 1991] has described paper drawings as compared to CAD object models as "relatively unstructured," and as compared to design concepts as a "low-level, communication language." Two dimensional paper drawings (usually one color on a white background) are only capable of representing a limited amount of information. For these reasons designers have had to resort to adding written text "specifications" (sometimes on the drawings, but usually in a separate document) to further convey the concept, e.g., blue chairs, copper wire, tooled mortar joints. These specifications complete the "building as frozen data" [Mitchell 1977], i.e., "what" is to be built, not "how" it is to be built. Due to the structure of the procurement system in the U.S., this data must then be exchanged to a contractor in another organization for use.

Upon receipt of this project data, or "contract documents," a contractor must perform feature extraction of the symbols on the drawings and combine it with information derived from the specifications to "interpret" what is to be built. Although a standard list of symbols is broadly recognized or can be defined on the drawings for representing objects, the objects represented mean different things to the contractor than to the designer. For example, a designer considers a wall to be a durable means of partitioning the 200 students; a contractor considers the wall to be a number of concrete blocks and mortar that will take X amount of time and Y amount of money to complete. Therefore, the contractor must interpret the symbols and text from the paper drawings and specifications and then structure them into numerical data by which he can calculate quantities, procedures, cost and time. See Exhibit 1 for Cherneff's drawing links schemata.

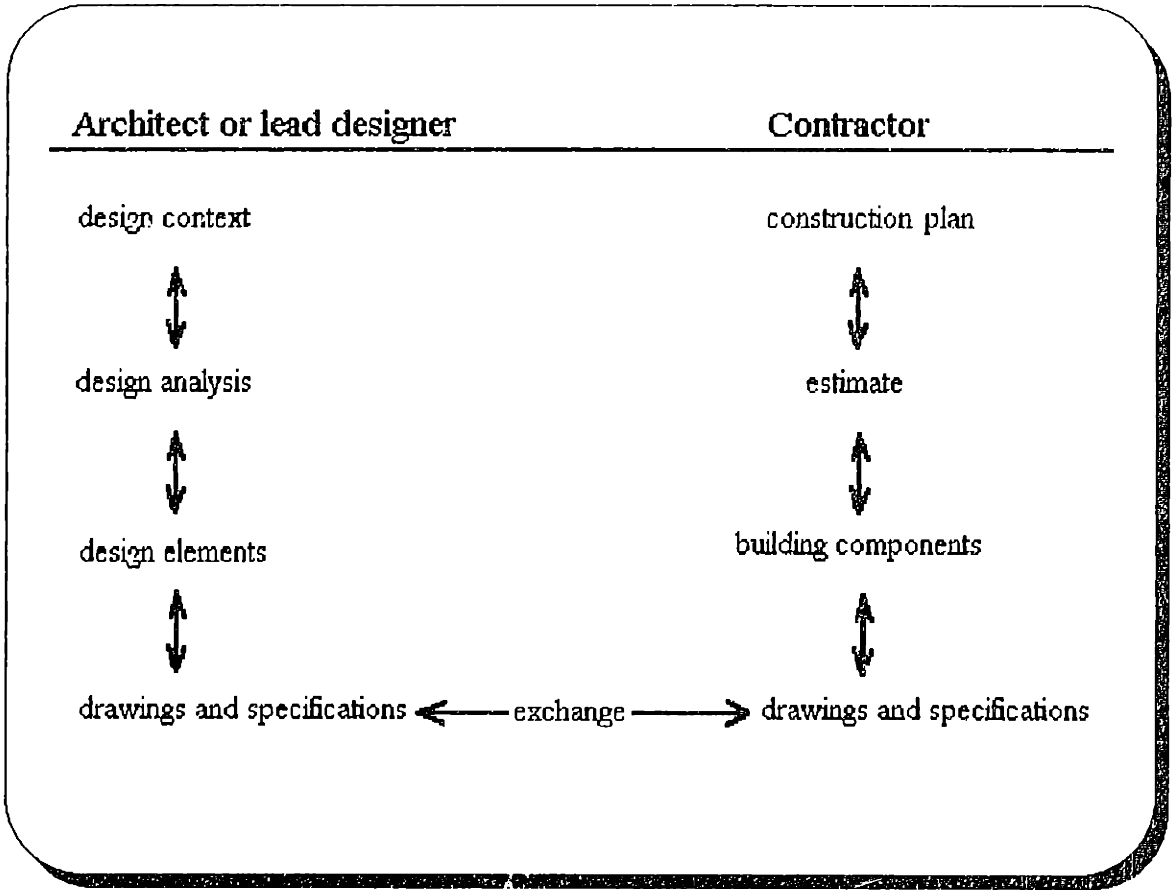


Exhibit 1

Designer-Contractor Communication: Drawing Links Schemata

(adapted from [Cherneff 1991])

The process of converting drawings and specifications into data introduces many practical problems. First, a contractor may interpret an object differently from the designer's "intent" due to a misunderstanding over a representation symbol. Second, it is a difficult task to coordinate the drawings with the referenced specification, which, to make matters worse, rely heavily on further referenced standards and practices. This system, exchanging information at the lowest level through graphic representations and text descriptions, has been the only viable system since the separation of the design and build functions in the 19th century, which will be discussed in the next section.

To accomplish the goals of this thesis, i.e., to share information from designer to contractor without interpretation, a better system for transferring information needs to be established. The improved system must establish a means for the designer to model the project and structure the data into a usable form for the contractor. This must be accomplished with a standard method for representing the design models and their entities, which, with the fragmented state of the industry, will be difficult to say the least. Clearly, some information such as construction methodology, should remain the domain of the contractor and the contractor will continue to have to structure certain data from representations like drawings to analyze the data. However, recent advancements in databases and three dimensional CAD make it possible to easily exchange this information in one set of contract documents. The system will not only integrate the flow of information vertically from designer to contractor, but also horizontally from designer to sub-consultant and from general contractor to subcontractor. All AEC professionals need to understand the information the other professions are interested in and construct a model that provides such.

C. British Bill of Quantities System

The building teams today in the U.S., Britain, and former British Commonwealth states are quite similar with one notable exception to be outlined in this section. The teams generally consist of a client, an architect/ engineer, sub-consultants, a contractor, specialist subcontractors, material suppliers, and public agencies. The team has developed through a long evolutionary process, beginning with the craft guild system in medieval times [Mitchell 1977]. Masons, carpenters, smiths, tile setters, plumbers, glaziers and painters educated themselves along craft lines, and then all banded together. They would usually be led by one or more "masters" from the masons or carpenters who contracted with clients to coordinate the design and construction. The cost of services was usually determined after construction was complete based on the costs expended.

The increase in construction after the great fire of London in 1666 brought about three significant changes. First, the craftsmen organized along craft lines into small enterprises, similar to the present day specialist subcontractors. Second, the increasing sophistication of the construction required a central "architect" to understand and coordinate all the crafts. The architect contracted with the client to perform design and construction. Third, work began to be paid for by piece-rates, and for this reason a "measurer" evolved to measure completed construction.

Around the time of the industrial revolution in the late 19th century, preparing design and coordinating construction became so complex that "contractors" emerged to specialize in the coordination. They were usually successful masonry or carpentry firms. The contractors began to change the role of the measurers to a preconstruction role, calling them "quantity surveyors" who reviewed the architects' drawings and determined the quantities on which the subcontractors should base their bid. The other significant development was the differentiated status of the "engineer" from the architect. In the 20th century as building technologies proliferated (e.g., mechanical, electrical, and new building materials), specialized architects and engineers emerged and worked as sub-consultants to the lead architect or engineer. There was also a significant increase in the specialization of subcontractors. The other noteworthy development of this century was that the quantity surveyor began to report to the client or architect, who then provided the "bill of quantities" to the bidding contractors. Although there are many variations of the building team's members, organization and responsibilities today, they generally conform to the description provided, except for design-build contracts.

The one notable exception alluded to above of the U.S. procurement system from the British system is that the quantity surveyor never emerged in the U.S. Rather, U.S. clients elected to have each bidding contractor estimate the quantities of materials required to complete the designer's intent, and base their lump sum bid accordingly. The British quantity surveyor not only prepares a Bill of Quantities (BQ) for the bidding contractors, but also budgets preliminary designs and manages fiscal matters such as interim pay requisitions and change orders during construction.

Since this thesis proposes that designers provide quantity survey information to contractors through a CAD database, it is helpful to review carefully the role of the quantity survey profession in the British system today. Quantity surveyors (QS) are trained in Britain and most Commonwealth countries through a college degree in quantity surveying, with some students earning advanced degrees. They are taught to interpret drawings, to understand the building materials, to gain knowledge about unit prices, and to perform takeoff in the most efficient manner. Paramount to their education is that they learn to prepare and present takeoffs in accordance with the Standard Method of Measurement (SMM). In Britain the SMM is developed by the Royal Institute of Chartered Surveyors (RICS) and sanctioned by the English government. Commonwealth countries similarly develop and sanction their own SMM. In fact, most European countries have a similar system. The SMM is updated every few years as new building materials and construction methods are introduced to the market, and is currently in version SMM 7 in Britain.

The client hires the quantity surveying firm as a consultant as soon as or even before the client hires the designer. The QS develops conceptual cost estimates and works with the architect/ engineer throughout design to attempt to keep the design within the budget. The QS does this by performing intermediate takeoffs, matching the quantities with a historical cost database and project specific knowledge, and suggesting design revisions as necessary. When the design is complete, the QS performs a very detailed BQ which is distributed, usually in an 8-1/2 X 11 paper format, to the bidding contractors. For a comparison, the BQ is usually as many pages as the project specifications.

The contractors, called "tenderers," base their bid on the quantities listed in the BQ, and submit a lump sum tender amount. Any additional materials required to construct the design are paid for via a change order based on unit prices. Similar to the U.S. system, some unit prices are requested in the BQ bid documents. Others must be negotiated if and when they occur. It is crucial to understand that the tenderers are also provided a complete set of drawings and specifications, that along with the BQ, become the contract documents. To prepare their estimates and bids, the tenderers carefully review the plans and specifications to determine construction methodologies, scope of work responsibilities, and scheduling. Upon gaining an appreciation of the work required, the tenderers apply waste factors and unit prices to items in the BQ, add in the cost of construction equipment and other temporary means, and then apply applicable markups. More information can be found about the British quantity surveying profession in [Turner].

Contrary to the popular beliefs of many American critics, the BQ has never been intended to serve as the complete means of information for bidding contractors. Rather, the BQ serves to complete the task of interpreting graphic primitives from design drawings into geometric data, and then structures the data into a familiar set of building components for the tenderers in order that they may analyze it. This is precisely what the previous section attempted to suggest, except to say that it may be possible to exchange the structured data without the third party QS.

One may wonder what the advantage is of the present British system to the present U.S. system since the same tasks are performed in each system, just without a separate quantity survey firm in the U.S. The advantages begin during design by involving a party that can convert design information into construction information, and hence prepare accurate cost estimates. As described in the previous section, generally architects and engineers are trained to envision objects in a domain schema that does not include construction methodology. The QS provides an economic basis for optimizing design, and imposes a rigid discipline on the client and designer to make up their minds early before committing to designs. Additionally, the designer can review the BQ with the QS to determine if there are any obvious errors or omissions in the design and the BQ. (Section D will describe the U.S. system's alternative to having a QS budget a design.) The second advantage of having a QS is that all bidding contractors tender based on the same scope of work, and not a set of drawings that requires interpretation, which subjects the bids to different interpretations and errors. (Section E will describe the serious problems that result in the U.S. system due to different interpretations.) This reduces friction during the construction phase by vastly reducing the amount of change orders since there is a clear commitment between client and contractor as to what needs to be built prior to entering the contract. The third, and possibly strongest, advantage of the British system is that the cost of preparing a takeoff is not duplicated by the tendering contractors, which may number ten or more. Experts have estimated the cost of preparing a takeoff to be 70% of the total cost of preparing a bid [Novitski, September 1992]. Although the cost of preparing a bid is rarely reimbursed to unsuccessful or successful bidders in the U.S. or Britain, the cost of bidding is added to the contractors' cost of doing business. The British system takes into account the fact that contractors as an industry pass on added costs of doing business indirectly to clients in the form of higher fees, and therefore their clients support the QS system. (Section F will describe the ramifications of U.S. system's alternative to a common BQ.)

D. Design Budgeting Procedures

A typical project may go through as many as five estimating stages. The first four are during design, and the fifth is by contractors during bidding. Designers or the client will develop a conceptual design (CD), considered to be 5% of the way through design, and a rough conceptual estimate based on one or both of their previous experiences on similar projects. If neither has experience in that type project, an outside consultant may be brought in, or unit price catalogs may be referenced. The estimate will be based on either square footage of space or unit capacity, e.g., MW of power, MGD of water treatment, etc. The estimate will be factored for specific aspects of the project, including physical aspects and less tangible aspects such as the labor market.

An estimate is usually calculated at 30% progress, or schematic design (SD). It is often performed by someone outside of the designer or client, usually a construction manager or an estimating service. Costs are estimated based on rough calculations of material assemblies, e.g., structures, walls, systems. Modifications are proposed if the cost is out of line with the conceptual budget. A 60% progress, or design development (DD), estimate is performed on some projects. With DD drawings most materials and material assemblies have been selected and located in the design, with only the details left to be designed. Although it may not be possible to apply accurate unit prices at this time, it is possible to develop a fairly accurate quantity survey at this time. Most projects have an estimate performed by the consultant at 90% progress, which is the completion of working drawings (WD). Depending on the project, it may or may not be at the same level of detail as a contractor's estimate. Comments by the consultant are worked into the design. At 100% the completed drawings and specifications are issued as construction documents (CD) to bidding contractors, and accuracies of the preliminary estimate are determined when the bids are received.

It is important to note that there is no customary attempt by designers to keep track of costs while objects and materials are designed into the project. Rather, there are the intermediate checks, which in some cases go from 30% to 90% design between checks. A designer may not realize that during DD and WD he or she may have severely exceeded the budget, making it difficult to revise the design substantially. What is worse is when a 90% estimate is not very accurate and construction bids require that a substantial redesign be performed. In these cases what usually happens is that "surface" elements are eliminated or reduced since they require a minimum amount of redesign time. Surface elements include architectural finishes, fixtures, and amenities, as opposed to the facility layout and size or to the underlying structural, mechanical and electrical systems whose design was established much earlier.

Recent convention terms the elimination or change in quality of surface items as "value engineering," although this is an abuse of the phrase that was originally meant to find a less expensive way of accomplishing the same design goals. Value engineering is intended to reduce the construction costs to the budget. Value engineering sometimes involves the contractor when the contractor has a much better idea of where the costs are in a project than the designer does. This creates an unfortunate situation for clients who are often under schedule pressure to make value engineering choices outside of a competitive bid situation. One client complained that he knew he "only got back $.80 on the dollar during value engineering" and "would have to pay $1.20 when we often realized late in the project we really needed the item." [confidential source]

It appears that by having to rely on outsiders to takeoff and estimate the costs of their designs, designers have limited independence and ability to adjust designs to the most optimal combination possible. The fact that designers make no effort to keep track of specific costs during design ought to raise a red flag for some form of automation that would not interfere with design objectives, yet give designers an ability to keep a closer track of the costs of their designs. Recently a few applications have been written for CAD programs that keep track of objects and material assemblies as they are added to the files [Novitski April 1993]. Although the applications were not developed from a contractor's need-for-detail perspective, they are a step in the right direction for truly integrated construction.

E. Effect of Drawing Interpretation

The most common form of construction procurement in the U.S. is to select a contractor by the lowest bid for a common set of drawings and specifications. This creates tremendous pressure on the bidding contractors to estimate accurately the quantity and cost of materials required. Underestimating by just a few percent can have serious ramifications since markups for fees are usually in the 3% to 8% range. Overestimating by just a few percent, on the other hand, can easily make a contractor uncompetitive. It might appear that if contractors sharpen their estimating skills, problems with the system will be reduced. This will no doubt improve the situation, but the real underlying problem is that each bidding contractor establishes a slightly different interpretation of the requirements of the same set of drawings and specifications. The pressure of the situation is to interpret the minimum whenever there is any doubt about the requirements.

This issue of interpreting the minimum is the result of many problems with the drawings and specifications system. The first is that drawings rely on a standard convention for graphically representing objects that is not always so standard, i.e., a symbol may mean one thing to the designer and another to one or more contractors. Due to the fact that there are estimated to be over 360,000 different building products [Mitchell 1977], it is difficult to combine all of a product's attributes into a symbol. For this reason specifications evolved. The problem with specifications, however, is that they must match up with the drawings that are a physically separate document. Often the two contradict each other, or worse, contradict themselves. Also, an object may be indicated in the specifications but not illustrated on the drawings, or vice versa. Clauses in the contract provisions that instruct the contractor what to do in the case of a conflict rarely cover the range of possibilities. Some conflicts are discovered during the bidding phase, but many are not discovered until during or after construction.

A second problem with drawings and specifications is that they rely to an extent on "common knowledge" of a building's or facility's requirements that is not included on the drawings and specifications. The problem with these "obvious" requirements is that "obvious" can be very subjective and ambiguous and not always be so obvious to all parties. Along the same lines, designers and contractors currently have a very unclear separation of responsibilities for maintaining building codes which are different in every part of the country and even different inside parts of states and counties. The contractor is forced to make interpretations of the requirements to complete the project in accordance with the design context (that the contractor is not familiar with) and building codes, which might be in conflict with the drawings and specifications.

The key to understanding the problems that the current system (and its need for interpretation) creates is to realize the ramifications that it creates for construction. As described previously, contractors are under pressure to estimate the minimum amount of materials required to be in accordance with the drawings and specifications. When a conflict arises the contractor is tempted and usually forced to include the least cost item because he or she understands that the other competing contractors will do the same, and he or she cannot afford to lose the bid due to a conflict he or she did not create. The same happens when an obvious object is absent from the drawings or specifications. Often an elevation detail that is needed to see an obvious item is not included. In both cases the contractor's reaction depends on the obviousness of the disparity, which, as noted previously, can be extremely subjective and ambiguous.

As a result of the contractor estimating the least cost of conflicting items or not estimating the cost of ambiguous items, the client and the designer do not receive the product they thought they were to receive or are faced with an extra cost request from the contractor to provide an item that was not clearly called for in the drawings or specifications. This is the start of the familiar "change order war." Contractors claim that they only estimated what could be reasonably inferred from the drawings and specifications. Clients and designers claim that the contractor should have been aware of the requirements, and is requesting change orders to make up for estimating errors. It is a common perception--but probably only true for a small group of questionable contractors--that many contractors bid work with little or no profit included in hopes that they will take advantage of an erroneous and ambiguous set of drawings and specifications. Allowable markups on change orders are customarily larger than that included by contractors at bid time.

These change order discussions usually begin towards the beginning of a project when a misunderstanding about the requirements is discovered. The result of the first change order discussion often sets the tone for the balance of the project and whether it results into a "war." This is the heart of the adversarial relationship between designers and contractors. Designers feel that contractors are attempting to increase their profits at the expense of the designers' professional reputation to prepare a complete set of drawings and specifications. The client expects the designer to have prepared a complete set of contract documents, and sometimes leaves the additional cost to be paid out between the designer and contractor. This exacerbates the situation. Contractors often believe designers attempt to belittle them and have them absorb the costs of the designers' errors and omissions.

Change order wars begin with low level negotiations (between each party's project managers), and may proceed to high level negotiations (between each party's principals plus legal counsel), mediation (a new form of alternate dispute resolution (ADR)), arbitration, or litigation. Each step involves increasingly precious managerial resources and enormous legal costs that are added to the industry's cost of doing business and eventually passed on to clients. In 1991 there were over $1.4 billion of arbitration claims filed in the U.S. relating to construction, or approximately 0.6% of total construction volume. 47% of the 5189 claims were between contractor and client, and 8% were between designer and client (contractors usually have no contractual recourse to designers). [American Arbitration Association] The negotiation, mediation and litigation claim amounts are not available, but are considered to be a multiple of the arbitration claim amounts. Nor is it possible to determine accurately the percentage and amount of the claims relating to misinterpretation of drawings and specification. However, the author estimates that misinterpretation is the original basis for filing well over half the claims. In a sample of 34 construction litigation cases 20 of the cases involved "conflict about interpretation of contract concerning about obligation, extra work and cost." [Tanaka] The cost and friction added to the industry from these misinterpretation problems are a continued cause of fragmentation to the industry and benefit none of the three parties.

F. Takeoff Procedures and Costs to the Industry

It is important to understand that after electing to bid on a project a contractor goes through a number of stages in performing an estimate, beginning with reviewing the drawings and specifications to ascertain the major components and trades of work required. Responsibilities are broken down within the firm into assignments (which may be from one to one hundred, depending on the size of the project), usually along the lines of CSI division format or work areas. Multiple subcontractors for each trade are contacted to insure that they will be performing an estimate and submitting a bid. Subcontractors will perform similar steps and may bid to any combination of the other general contractors.

The next step is for each estimator to perform the quantity survey, or takeoff, of his or her trade or work area, and combine it with unit prices for a divisional preliminary estimate. Equipment costs and general requirements may be added separately from the unit prices. All the preliminary estimates are then combined into a job preliminary estimate. Firm subcontractor prices will be added to the estimate, and then the estimate will be checked to the best extent possible to ensure that nothing is omitted. The contractor will calculate the estimate a final time into a firm bid that is then submitted to the client or its agent.

During takeoff each estimator will work through the drawings and specifications with some combination of scales, multiple colored markers, and electronic digitizers to measure materials and installation required. There are often different attributes measured for materials and installation to make the cost estimate as accurate as possible. Installation may include temporary construction, e.g., scaffolding. However, all installation attributes can be calculated from the material attributes of occurrence, length, area or volume. "Time" is not a takeoff, but rather is a method often used to calculate the cost of an item.

Different estimators will takeoff different attributes in an effort to model the construction to their own or their firm's liking. Takeoff is actually calculated from a series of measurements and may be calculated by the estimator or a computer program. There are three types of takeoff: 1) Some *prefabricated objects* can simply be counted from their indication on the drawings or by their requirement in the specifications. However, the prefabricator will have to perform a more detailed takeoff such as like type 2) or 3). 2) Field applied *materials* require that measurements (length and/ or width and/ or height) be used to generate quantities required. The calculation may be performed by hand or a computer. Typically, one or more accessories (e.g., fasteners) are listed in the specifications and may calculated based on the quantity of material required. 3) *Assemblies of materials* may be used to measure a combination of materials and different attributes (material and installation) for each material with one set of measurements (length and/ or width and/ or height). Usually a computer program calculates the takeoff for an assembly, although the process is the same if it were to be calculated by hand.

Knowing what attributes to measure for takeoff requires the knowledge of an experienced estimator, as obviously does the choice of accurate unit prices. However, one can see that measuring attributes and generating a takeoff, although both can be quite detailed, are low level tasks that are painstaking and error-prone. Therefore they are perfect candidates for automation.

It might amaze some to discover how much effort and money is spent estimating construction in the U.S., a great majority of which are fruitless endeavors for the unsuccessful bidders, general and sub contractors alike. As stated previously, approximately 70% of the effort and cost of preparing an estimate occurs in the takeoff phase, both at the general and sub contractor level. Due to the nature of the system there is duplication among competitors--both general and sub contractors--horizontally, and among collaborators vertically, i.e., general and sub contractors working together. The costs passed on to the industry are enormous. Exhibit 2 derives the potential costs expended on takeoff alone for a typical $30 million commercial building project with 5 general contractor bidders and 105 subcontractor bidders. An industrial project would require roughly the same amount of takeoff, only with a smaller number of trades. The costs approach $140,000, or 0.47% of the project cost. To extrapolate this percentage cost for the entire construction industry, an estimate needs to be made for the amount of "plans and specs" construction on which multiple contractors bid each year. Although this figure is not available, it may be a conservative assumption that of the $239 billion of nonresidential construction completed in 1992 [MacAuley] $220 billion was procured by "plans and specs bidding" either at the prime or subcontract level. Extrapolating 0.47% of $220 billion generates a cost of $1.03 billion to the industry for redundant takeoff costs alone.

		Typical $30 million project		
General Contractors				
4 estimators	for 6 days	@ $250/ day	* 5 bidders	$ 30,000
12 estimators	for 1/2 day	@ $250/ day	* 5 bidders	$ 7,500
				$ 37,500
Major Subcontractors	(mech, electrical, plumbing)		(5 bidders per 3 trades)	
2 estimators	for 6 days	@ $250/ day	* 15 bidders	$ 45,000
Substantial Subcontractors	(earthwork, concrete, masonry, steel,	millwork, drywall, etc.)	(5 bidders per 6 trades)	
1 estimator	for 5 days	@ $250/ day	* 30 bidders	$ 37,500
Minor Subcontractors	(20 trades)		(4 bidders per 20 trades)	
1 estimator	for 1 day	@ $250/ day	* 80 bidders	$ 20,000
		project specific costs to the industry		$140,000
		% of project costs	$140,000/ $30 million	.47%
		annual costs to the construction industry	.47% * $220 billion	$1.03 billion

Exhibit 2

Costs of Takeoff to the Industry

G. Design-Build Integrated Systems

Design-build firms have many advantages over the ad hoc relationships established by design firms and contracting firms in the typical procurement process. Of interest to this thesis is the fact that, although there may be different individuals in the design-build firm handling design and construction, the exchange of information is subject to much less translation and interpretation. The exchange is greatly facilitated by the physical relationship, which may include electronic systems and cultural relationships, which may include mutual objectives and incentives for designers and constructors. Design-build firms understand much better the need for true integration across all phases and disciplines of both design and construction. Hence many have developed their own proprietary CAD systems (or built applications on top of commercially available CAD systems) that include many aspects of complete design and construction integration, including detailed quantity survey systems. These design-build firms have proven that this proposal for CAD systems to generate quantity surveys is possible when there is one central control.

Design-build firms have used such systems as a competitive advantage in obtaining business, but primarily for industrial or civil work where they can bid on a scope of work defined by "function" (like MW of power) and not "form" (like the architectural details of a building) which is much less definable. Even within design-build contracts, though, there are large subcontracts that are procured on lump sum bases. Sometimes design-builders share quantity survey data with their bidders, but usually they act like designers and do not share this information for a number of reasons, although their CAD systems often generate the data. It might be safe to assume that, due to the country's desire for fairness and accountability in construction procurement (especially on architectural "form" projects), design-build may never become the dominant procurement method. Yet, if designers and contractors will understand that their objectives and incentives are not mutually exclusive, but rather dependent, they will both benefit from developing systems that integrate with each other's. Unlike in a design build firm where a standard can be mandated, the task for designers and contractors interested in integrating their systems is to agree on a standard for modeling objects and representing design and construction data.

This chapter has attempted to prove that the current method of exchanging project information is inefficient. Particular inefficiencies are shown to occur in the development of quantity surveys. The chapter provides the British Bill of Quantities system and design-build integrated systems as alternative methods and implies that the U.S. AEC industry adopt a combination of the two. The implied System will not eliminate design errors, contractual disputes, or bad cost estimates. It will however, reduce or eliminate duplication of takeoff and disputes over misinterpretation. The next chapter analyzes the proposal to share quantity survey data electronically as a Composite Information System, and describes the benefits to the parties that participate and promote it.

Chapter III. Benefits of Proposed Composite Information System

The System proposed in this thesis is essentially calling for an electronic project database to be created by the project's designer and shared with the project's contractor. Osborn [Osborn et al. 1988] has referred to similar situations as a Composite Information System (CIS) since it requires the combination of two or more organizations' information systems. To get two organizations to develop a CIS, the promoter can resort to two types of motivation: *external* and *internal.* External motivation in this case would be a requirement from the outside, i.e., the client or large groups of clients such as government agencies, that the two parties adopt the CAD database system that creates and shares the quantity survey data. External motivation can be a very powerful yet dangerous strategy for implementing a CIS, and will be characterized in Section B. Internal motivation is given by the participating organizations.

A. Internal Motivation

The next three sections will describe in Osborn et al's. framework the three necessary aspects for internal motivation of designers and contractors: *bi-directional benefits, cooperative payoffs, and asymmetrical control.* These are depicted in Exhibit 3. Internal motivation has the advantage of encouraging participation by the users, i.e., to show each party "what's in it for me." Furthermore, internal motivation tends to be self-perpetuating as improvements from implementation are recognized.

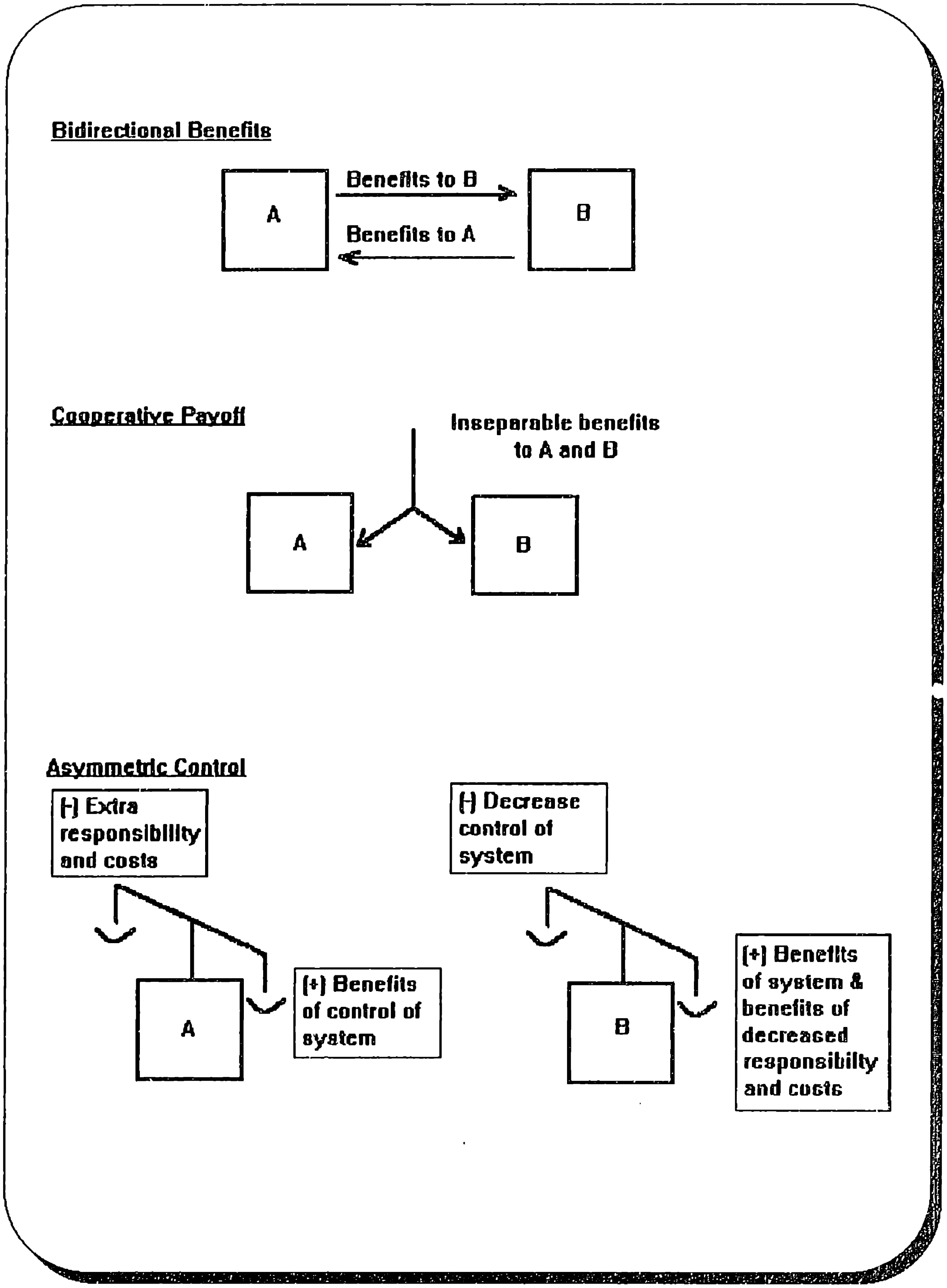


Exhibit 3

Approaches to Internal Incentives (adapted from [Osborn et al.])

1. Bi-directional benefits

Bi-directional benefits are those benefits that are related specifically to a participant in the CIS. These benefits are different for each participant, but they are not gained at the expense of the other participant.

a. Contractors

Contractors clearly have the most obvious benefits to participating in a CIS that provides them with quantity survey information. On the surface, a shared database with quantity survey data will eliminate or reduce their need to perform takeoff. This is true, but the deeper benefit is that they will reduce their costs of performing estimates (earlier it was proposed that the savings may be up to 70% of current costs) and hence increase their efficiency. This will reduce a contractor's cost of doing business, which, since most contractors charge their estimating costs against overhead, may be translated into larger profits on the bottom line of the company. Some of the savings will undoubtedly be used to reduce the amount of fee applied to a bid, and hence result in more successful bids. Exhibit 2 shows that a general contractor's takeoff costs might be 0.03% of the project cost ($7,500/ $30,000,000). Therefore, a general contractor who performs $100 million of revenue a year and is successful on an average of 1 in 3 bids (i.e., bids $300,000,000 of projects) may reduce its cost of doing business by up to $75,000 a year (0.03% of $300,000,000). General contractors who self-perform more and subcontract less of their work will recognize greater savings. If the savings are not added to the bottom line of the company's profit they will inevitably allow estimators to focus more clearly on their other responsibilities, and hence improve the quality of the organization. Many contractors rely on their project managers to double as estimators, often sacrificing the performance of one or both responsibilities. Allowing them to concentrate on their project management responsibilities would be very beneficial to the operation of the company.

A second benefit from the reduction in effort to generate takeoffs is that a participating contractor may be able to bid more projects with the same size estimating team. This should increase the number of contract awards. A better outcome might be that the contractor is able to maintain the same number of awards, but due to the greater number of bids increase its fees.

The third and most important benefit for a contractor is that a shared quantity survey system would allow the estimating team to focus its efforts on performing a quality estimate. This would be accomplished by concentrating on analyzing and selecting unit prices to be applied to the quantity survey. Unit prices found in historical databases are applicable to a broad average of situations, and may not be accurate enough for a specific project or situation. Effort could be made to locate more bidding subcontractors, and to work more closely with them to ensure that scopes of work for the entire project are covered. Winding up with a "bust," or a scope of work inadvertently left out of the estimate, is a common occurrence for a contractor. Scopes of work may be adjusted between subcontractors to achieve the best combination of core competencies. Additionally, the quality of the estimate may be improved by allowing the estimators to carefully plan construction methodologies and sequences. Most contractors defer detailed attempts at these tasks until they are awarded a project, often realizing a problem when it is too late to include the costs in the estimate.

A fourth benefit for a contractor is the reduction in risk of completing a project within the estimate. Depending on the contractual agreement regarding the shared quantity survey, the responsibility for guaranteeing quantities will change. If the responsibility for guaranteeing in-place quantities resides with the designers, then risk of takeoff errors will be eliminated, except takeoff of temporary construction items like scaffolding that must undoubtedly remain the domain of the contractor. If the quantities provided by the shared quantity survey system are not guaranteed by the designer then the contractor's takeoff errors will, at worst, be reduced due to the ability of the designer to use the CAD system to its full intent. Some contractors may still elect to perform their own takeoff which will provide them with a check of the two takeoffs. Either way, contractors will be reducing their risk to takeoff errors.

b. Designers

Although not as apparent, the bi-directional benefits to designers who participate in a CIS that generates a quantity survey are just as important as those benefits to contractors. First, by designing on a CAD system that keeps an accurate quantity survey, designers can keep a much better track of the projected construction costs of their designs if they couple the quantity survey with a unit price database. In comparison to the intermediate costs checks described in the last chapter, this may be a monumental improvement by allowing designers to work and think in terms of cost as they design. This will bring the construction documents more closely in line with the budget and eliminate or reduce the need for today's definition of "value engineering." Second, by doing so architects and engineers will be able to design more value into their projects.

Architects and engineers sell their services for new projects by describing the quality of completed projects and how little the construction cost. Architects and engineers will be able to claim that they can design "more bang for the buck."

A third benefit for designers is that they will be able to review a quantity survey of their completed designs and check the design for obvious errors and omissions. Currently designers have to scan their own drawings for their graphic representations to check for errors and omissions. On some projects designers conduct their own quantity survey or hire a consultant to do so, but this is an additional cost. To be able to see their design information represented in a contractor's format will be a powerful tool for designers. It will help to head off change order wars. Additionally, the CAD object model system proposed requires that design be performed in 3D which offers a range of improvements for the design process and for preparing quality design documents; for additional information on 3D design benefits see [Smit 1992] and [Reinschmidt et al. (1991)]. The crux of the benefits is that 3D gives designers a tool to check for--or in many cases eliminate--interferences. The quantity survey and 3D abilities make it easier for the designer to prepare a much more complete and accurate set of drawings.

A fourth benefit for designers is that they will be performing an additional service and will be eligible for additional fees.

2. Cooperative payoffs

The second element of internal incentives for adopting a Composite Information System is *cooperative payoffs*. Cooperative payoffs are the benefits gained from use of a

CIS that are common to both parties, designers and contractors. Stated differently, cooperative payoffs are the benefits to the collective AEC industry. The first payoff is that by having reduced their cost of doing business and their risk, contractors may reduce their fees accordingly. This will lessen the unit cost of construction and allow clients to contract for more building or facility, in terms of size or performance. Lower construction costs might also make the difference to a project's financier whether the project is financially viable or not. The effect will be to permit more construction and hence create more contracts for those designers and contractors participating in the CIS. On a specific project basis, a client may enjoy watching the relationship between a designer and contractor who share information through a CIS and elect to use them together again as a team.

A second payoff is to increase the competitiveness of the U.S. AEC industry and its players in relation to foreign AEC industries and their players. This may help to reverse a trend started in the 80s when foreign firms began to gain an increasing share of the U.S. market. The payoff may also result in increased competitiveness for foreign construction work. Whether the competitiveness is obtained as a direct result of using CAD systems with quantity survey output, or not, is irrelevant. The important factor is that a CIS will help to bring together the design and construction cultures, and to allow each to understand the other's domain better. The benefits of creating a central project database for use by designers and contractors go way beyond sharing a quantity survey. Linking information technologies to construction is a step the U.S. AEC community must promote in hopes of ever catching the Japanese in construction automation. A number of Japanese contractors are perfecting automated construction systems controlled by a project database, and soon expect to use them as a competitive advantage [Normile].

A third cooperative payoff is that improved change order management will reduce designer-contractor friction. The requirements of the contract documents for the contractor will become much more clear and misunderstandings will not develop as easily. Additionally, when changes to the documents are necessary, the scope of the changes will be clear. Often in the current system changes are made to the documents during construction, but disagreements emerge as to the extent of the new requirements versus the existing requirements. With the original and the new designs linked to a quantity survey database, one need only to subtract the values to find the quantity differences. A better understanding over change orders will reduce the need for negotiation, mediation, arbitration and litigation, and hence save money for both parties. Beyond economic payoffs, however, there is a magnificent potential improvement in morale on a project through improved relations. For both parties to know that they do not have to begin a project by preparing their case for a change order war, or for each party to better understand the other's objectives, has potential to create a team environment with each member working to assist another, even if they work for different organizations.

3. Asymmetrical control

It is important that both parties have a hand in developing any Composite Information System in order that each party's needs and concerns are built into the CIS. However, due to the fragmented state of the design and contracting professions it is not possible for even a group of designers and contractors to get together to establish a standard system for the industry at large to adopt eventually. For this reason, a central agency such as the National Institute of Building Sciences (NIBS) will be required to develop a system that benefits all parties of the AEC industry. NIBS is presently promoting a number of standards for representing design information, including methods to integrate specification information with drawing information. (For more information regarding these efforts see [Rutherford].) If designers are to willingly use the proposed CAD system, it must operate in a manner that does not obstruct present design methods and practice. Therefore design groups such as the AIA, ASCE, ASME, etc., should be closely consulted. Contractors, too, must be consulted in order that the quantity survey output is in a useful format.

Although both parties need to develop a CIS jointly, one party must operate it. The difference between this CIS proposed and most CISs is that this one does not require a radical shift in business practices. In this case it is clear that designers should operate the system since most have been working with CAD for years. Additionally, designers are the first party involved after the client and begin the flow of information. Contractors will not even be required to operate the CAD system, but only to access its output in database or spreadsheet form. As contractors become more familiar with the system they will begin to explore the entire system's abilities and may attempt new applications. Meanwhile, though, contractors will be willing to give up control of the system in return for the benefits described above.

B. External Motivation

As described previously, external motivation can be powerful in establishing the use of a CIS. External motivation in this case would be a requirement from the outside, i.e., the client or large groups of clients such as government agencies, that the two parties adopt the CAD object model that creates and shares the quantity survey database. A successful example of external motivation for a CIS can be seen in a recent large shopping mall project where the client mandated the sharing of CAD files with contractors, effectively slicing through legal and proprietary issues [Post]. The advantage of external motivation is that it can be quick, decisive, and establish more uniform standards. The disadvantages of external motivation include that, if the subordinates see no benefit to the system, they will not use it to its full potential, and the cost spent implementing the system may be wasted. Another disadvantage is that, if the subordinates see a threat to their power base, they may attempt to sabotage the system in an attempt to return to the original status quo system. A third disadvantage, especially in this case where the owners of construction are a very fragmented group of motivators themselves, is that there usually is not a strict power hierarchy to easily implement CISs. Nonetheless, it is most likely that the work of this thesis will require promotion and even requirement by clients to ever be adopted by the industry. Clients, however, have much to gain from this CIS and--after initial development costs are absorbed--nothing to lose!

1. Clients' benefits

The most powerful advantage for clients whose projects use the proposed System is that the cost of construction will be reduced. As noted previously, contractors pass on their estimating costs to the industry in the form of higher fees. This is the passing on of the cost of doing business. By reducing or eliminating the takeoff portions of the estimating costs, the costs to the industry will be reduced by as much as $1.2 billion, or 0.47% of construction cost, as derived in Exhibit 2. Any one client will have difficulty comprehending any savings on one project by mandating a CAD object model with quantity survey database, but the sum total to a series of projects will show an effect. For this reason it is crucial that large clients such as the Army Corps of Engineers or General Services Administration begin to require such integration of information. Contractors also pass on higher premiums in their fees and in contingencies for risk or takeoff errors. Depending on a project's contractual terms, a furnished quantity survey will reduce or eliminate takeoff errors to a contractor. Although it is difficult to measure, the author estimates the potential reduction in fees to be worth as much as 0.50% of project costs. This is a savings that any one client could realize on one individual project. Clients will be required, however, to carry contingencies in their budgets that contractors previously carried in their estimates. However, since designers will be able to run interference checks on the 3D CAD system and review the quantity survey, the errors and omissions will be reduced, and hence the contingencies may be smaller.

The total savings from the takeoff costs (0.47%) and the reduction in risk (0.50%) may be as much as 0.97% of construction costs. There will be, however, an added cost from designers to purchase and operate the System, but it is expected to be minimal: 0.10% or 0.20%. The Conclusion will summarize a notable cost savings that clients will appreciate.

The second benefit to clients who support such a CIS is less tangible than the direct cost savings, but it too has long term financial benefits. By requiring such a CIS as the quantity survey system, clients will be supporting the team approach to sharing information between parties. The industry has popularly coined this as "partnering" as an attempt to head off or uncover problems early, share estimate and design information, and agree on solutions and costs quickly. The team approach reduces friction between the parties, especially between designers and contractors. Reasons for misunderstandings and arguments are reduced or eliminated by making the quantity survey defined and objective, as opposed to the present system where it is subjective to each contractor's interpretation of the drawings and specifications. With a decrease in the friction comes a willingness by all parties to negotiate and solve problems as they arise, as opposed to stock piling them in a war chest for possible litigation. As described in Chapter II, the industry spends tremendous effort on managing problems and litigation and tremendous costs on funding litigation. On an individual project or on an industry wide basis the team approach can reduce litigation and save clients money.

The third benefit to clients for applying external motivation for the adoption of such a CIS is that the amount of value built into a project can be increased. Value can be defined as designing and building for the client what provides the most use, or utility. An increase in value can be accomplished by improving the budgeting and preliminary estimating techniques described in Chapter II. Many projects come in at bid time over budget and must be subjected to value engineering, which as described previously is an attempt to lower the project cost by changing or eliminating the surface items. It is usually too late to redesign the layout of the facility where more valuable changes might be made. All the while during value engineering time and money are being lost. By using a CAD system with quantity survey capabilities and a unit price database, designers could spend their efforts to truly value engineer during the 60% to 90% design stage. Just as common are construction bids that come in far below the designers' estimates and clients' budgets. In these cases the excess funds are usually spent on surface items with contractors' markups that are far above what is normally included in a lump sum bid. By having better control over a project during design clients can increase their value in the project.

The next chapter will describe the issues and problems involved with this proposal that will help to explain why it is has not yet been developed and adopted.

Chapter IV. Problems and Issues of Proposal

There are obviously many issues obstructing the development of a full scale commercially available CAD system that generates a detailed quantity survey, or else there would already be such a system in place. The issues can be broken down first into organizational issues, i.e., what is it about the culture, structure or organization of the U.S. AEC industry that makes the players resist such a system? One might also ask the same question of the British AEC industry since their system of furnishing a Bill of Quantities appears to provide a prime organizational climate for automation. Both countries' industries share the same issues. The second type of issue is technological, and it should be pointed out that these issues are much more easily surmountable than the organizational issues that have been cemented in professional responsibilities for over 100 years. The reluctance in the industry to change existing procedures is monumental. This chapter will describe first the organizational and then the technological issues obstructing the development of the proposed System. Chapters V and VI will suggest solutions to the organizational and technological issues in order.

A. Organizational

As described in Chapter II, the U.S. AEC industry is extremely fragmented, meaning there are no dominant players and few standard operating procedures. Project responsibilities are usually divided between two parties, designers and contractors, with different objectives. These characteristics of the organization of the AEC industry make it difficult to implement changes such as the proposed System for sharing a quantity survey database.

1. Issues involving designers

The following issues were raised by designers in a survey about this thesis proposal. Although many of the issues reflect practical considerations, the issues as a whole reflect the momentum of the accustomed design practices.

a. added responsibility

The first type of organizational issues come under the "what's in it for me?" category because designers see additional work they will have to perform to operate such a CAD system. First, designers will have to adopt and train on such systems to learn how to operate them properly. Three dimensional CAD systems are a whole new league above 2D systems, and defining every project entity in the 3D model as an object with attributes requires more work than the present 3D systems require. Next, during design architects and engineers will be required to provide additional detail to the model and answer questions for the linked database, tasks that contractors presently perform by manual methods. This additional work is additional responsibility, and is unpopular in an era when most firms want to specialize and limit their responsibility.

b. added liability

Additional responsibility in and of itself is not a problem to designers (assuming they are compensated for the added costs), but rather the resulting additional liability effect is. An architect described providing a quantity survey to a contractor as the "line we never cross" [Cherneff 1991]. Depending on a project's contractual terms, clients might require designers to guarantee that they will cover the cost of any in-place materials that exceed the Bill of Quantities, which will most surely encounter severe resistance. Alternatively, the client may be guaranteeing to the contractor that it will pay for via a change order any in-place quantities that exceed the Bill of Quantities provided by the CAD system. This creates an issue important to designers whether or not clients will develop a level of trust with them and really absorb the cost of omissions that will inevitably occur. Clients of the construction industry are often discouraged with the quality of service provided by designers and require that they pay for the cost of their errors and omissions, which can be sizable amounts for designers that are usually financially smaller than the clients or contractors. This creates a lack of trust between the clients and designers that rivals the low level of trust between designers and contractors. For designers to be willing to create and share additional information, a higher level of trust and a limit in liability must be developed.

c. will require designers to think like contractors

A fundamental problem in having designers operate the CAD systems that generate quantity surveys is the fact that designers are trained to design, while contractors are trained to build. Most architectural or engineering curriculums do not teach constructibility, which the persuasive 1983 Business Roundtable Report described as a leading undeveloped source of productivity gains [Business Roundtable]. Designers are not familiar with the steps required to build most steps of a project, and hence may not be qualified to understand where the costs are that need to be calculated in a quantity survey. As described in Chapter II, each discipline's designer has one view of a wall, while a contractor has an entirely different view of the same wall. A CAD system can assist a designer with knowledge-based prompts for each type of building material added to the project file. But can designers begin to comprehend the significance of the questions and make intelligent decisions? It might require additional education, not only in operation of 3D CAD systems, but in constructibility also. Does it make sense for designers to learn the basic skills that presently are the domain of the contractor? Many proponents of the existing system will argue that specialization into design and contracting and then into subspecialties for each discipline is the basis for the explosive productivity gains of the U.S. AEC industry in the past 150 years [Howard et al. 1989], [Mitchell 1977]. (It should be noted that recent reports show construction productivity including design and contracting to have declined in the latest two decades studied [Business Roundtable].) Proponents of the existing system claim that adding constructibility constraints to designers' responsibilities will disrupt their ability to create original designs, and inhibit their effort to complete designs on schedule.

d. changing from graphic primitives to objects

The basis of the proposed 3D CAD system is that every entry to the project file is a distinguishable three dimensional object with certain attributes described in the linked database. This is a fundamental change from the existing 2D CAD systems where a series of two dimensional graphics must be mentally configured together to represent three dimensional objects. To get designers to begin to work in an object mentality and not a line drawing mentality is a difficult task. This is especially difficult for architects more than for engineers because architects often need to sketch or draw to get the proper aesthetic look of a building set in their own minds. Additionally, many designers are uninformed and have the misconception that object-oriented design is associated with flat and square shapes that do not provide the detail and curvature that architects often desire to use.

e. cost to benefit ratio

The previous four issues all relate to the cost to designers in implementing such a CAD system. The CAD and database software that must be purchased will be more expensive than systems presently on the market because it will include a premium for the work necessary for developing such an in-depth system. Designers must also purchase training time for the users. There will be productivity losses during the initial stages of implementation and learning. The actual operation of the system might even require more effort than present systems and hence cost designers more. Finally, there will be a cost to maintain the software and keep it up to date with the latest standards for both file formats and construction materials. Considering these costs, it is a valid question to ask whether or not the benefit to cost ratio will be positive.

f. quantity survey information in the specifications

Another fundamental issue is the fact that currently takeoff information is gathered from the drawings <u>and</u> specifications. Specifications usually tell the contractor "what" type and class of materials are being described on the drawings, and often they describe materials and items that are not depicted on the drawings. The MASTERFORMAT® specifications list this in "Section 2: Products." Sections 1 and 3, "Submittals" and "Execution," respectively, describe "how" the materials are to be engineered and installed.

Simply linking a 3D object model that creates drawings to a database will not provide the necessary information to apply proper unit prices to objects listed in the quantity survey. Nor will it provide a complete quantity survey.

g. electronic data is not legally binding

The information revolution presently underway in corporate America has generated a number of social and legal issues concerning the way new business practices interact with present customs. One such issue is whether or not electronic information that is passed between two organizations is legally binding since it is relatively easy to alter electronic files. Present AEC practice is to stamp and sign the contract, the specifications, and every drawing, which together make up the contract documents. This is done so that there cannot be a dispute over one party modifying the contract documents after they are signed. It is not possible to stamp and sign an electronic file that is actually a series of magnetic or light impulses that make up a string of 0s and 1s that computers decipher into text and graphic information. It is important that designers give contractors the CAD and linked database files in order that they review the project on the CAD screen as well as by the printed drawings. The CAD screen will allow quick referral between the graphic design and the attributes in the database. Therefore there needs to be a method of exchanging the CAD and database files while ensuring that they cannot be tampered with or manipulated. Furthermore, to print out the database with the quantity survey may be an impractical task due to the potential volume of information.

h. contract terms for shared Project Database

Another legal consideration necessary for the use of the proposed System is how to define contractually the significance of the automated quantity survey. The quantity survey generated by the system could be accessed by contractors for information purposes only, or it could be designated as a binding Bill of Quantities. If it is designated as a binding Bill of Quantities there must be a whole new set of contract terms that define what to do in the case of an error or change. Although Bill of Quantities contracts are presently common in earthwork construction, the range of possibilities for disputes in the construction of buildings and facilities is much greater due to an enormous increase in the potential number of building materials and situations. To have bids and contracts based on unit prices for each material listed in the quantity survey could be an impossible task. Furthermore, each material may have many different unit costs based on its location in the project or its occurrence in the schedule. Even if the quantity survey is designated for reference and information purposes only, disputes may arise when there is an error. A new range of contract terms will need to be developed in order to manage both situations, but either way existing practices and momentum will be difficult to overcome.

2. Issues involving contractors

In addition to resistance from designers, there may be intense resistance from contractors who believe that a CAD system that automates takeoff will be a detriment to their business. Some of the following issues were raised in a survey of contractors.

a. reduction in responsibility and fees

Clearly, the contractors' responsibilities and risks will decrease, and, as proposed earlier, their markups applied to bids will inevitably decrease due to market forces. Many contractors will see this as a threat to their profitability and will resist it. Concerning responsibility for takeoff, individual estimators will see automated quantity surveys as a threat to their job and will strongly resist the movement. This may very well be a reason why such a system has yet to be developed in Britain because the quantity survey profession may see it as a means to their own end. Concerning risk of takeoff errors, some contractors are willing to take the risk in hopes of being successful and earning higher margins.

b. loss of differentiation and competitive advantage

Many contractors view their takeoff and estimating skills as a way to differentiate themselves from other contractors. In other words, they believe they use their skills as a competitive advantage to gain work by having more accurate numbers, presumably in quantity takeoff and unit prices, than the other bidders. To bid on a project where the designer used a CAD system that provides the same in-place quantity survey to all bidders would negate most of the competitive advantage from that contractor's takeoff skills. (Contractors must still obtain net bid quantities by applying proprietary waste factors to in-place quantities.)

c. role of general contractors may diminish

To have designers create a quantity survey that is available to all bidding contractors and subcontractors is similar to steps being taken by some designers to use

CAD models to assist in manufacturing (CAM). One interesting article [Novitski August 1992] describes one architect's ability to send CAD data of complex 3D shapes directly to fabricators to assist in their work, automatically preparing shop tickets and even linking directly to milling machines. The general contractor was completely bypassed. If all this information can be generated and passed electronically to subcontractors, the question arises: "What becomes the role or need of the general contractor?" General contractors will resist any movement that appears to build up the role of the designers and subcontractors and diminish their own role.

d. cost to benefit ratio

The cost for contractors to obtain the necessary hardware and software to review the CAD models and linked databases will no doubt need to be considered. In addition, the contractors must pay the cost of their employees' training and lost productivity meanwhile. Many believe that contractors, especially smaller ones, will resist the movement as financially impractical. They may not be willing to make the investment that will not show a net savings over manual takeoff procedures for two or more years. The cost to benefit ratio must be high enough to entice all sizes and types of contractors to purchase the system. If too many contractors elect not to purchase the proposed system software, its unit price to those designers and contractors that elect to purchase it may become too high to be practical.

e. sophistication of technology

Many believe that the average contractor (differentiating from the large design-build contractors) is not capable of operating complex computer systems like the

CAD or the database software. This may only reflect an adversarial position from some designers, but it is probably accurate to state that many contractors are apprehensive about adopting more complex computer systems. Many contractors have not realized a payoff from their recent information technology investments (like estimating and project management software) due to the difficulty in operating some of the systems. They worry about the costs of a CAD system and database, and whether if after all the training and maintenance there will be a net advantage. Only a small percentage of contractors to date are operating CAD systems, which are much more complex than estimating or project management systems. Some contractors will have difficulty adopting.

f. trust in the quantity survey

A final organizational resistance to the proposed system may come from contractors who will not trust the quantity survey derived by the CAD system. If contractors will not trust the quantity survey they will elect not to purchase the system and will continue to perform takeoff in a manual method. This will drive up the cost of the system to those who wish to purchase the system, possibly making it financially impractical. In addition to not trusting the quantity survey, even if it is designated as a binding Bill of Quantities, contractors may not find the level of detail or the organization of the quantity survey to their liking. Materials may not be measured in the units or method they prefer, and they may elect to perform their own takeoff. Until it can be proven that the quantity surveys generated from the proposed CAD system are accurate and useful, acceptance by contractors will be slow.

B. Technological Issues

There are a number of technological details that must be worked out for the proposed CAD system to be feasible. The details can be considered minor as the past 10 years have brought about enormous computer advancements, such as in microprocessor speeds, storage mediums, graphical user interfaces, networks, and many more areas. These advancements have brought computing down to an inexpensive, compact, user friendly, and yet powerful basis. Answers may be applied today to many of the technological issues raised in this section.

1. 3D versus 2D

The crux of the technological issues revolves around the way design data is to be modeled on the computer systems. The system relies on modeling which is creating a 3 dimensional representation of objects in a project. This is a whole new paradigm shift from 2 dimensional CAD that is a pictorial representation of an object from one simple view. Although there have been many advancements in 3D CAD from wire frame to surface modeling to solids modeling, there is still a tremendous amount of additional work required of designers to work in 3D. To complicate the matter further, the proposed system relies on linking the 3D objects to an external database that carries attribute information of each object.

2. Database disparities

The structure and composition of the external database are the greatest of the technological issues because the database needs to contain multiple views about each object for designers and another set of views for contractors. As described in Chapter II, designers view objects in terms of performance, and contractors view the same objects in terms of construction procedure and cost. The geometric properties (length, width, height, area and volume) of an object must be combined in one fashion to provide designers their view and perform calculations concerning performance. Contractors need to be able to see the same object in another view for construction requirements. The database must be capable of performing this. Additionally, each object will have an extensive list of attributes (which will be a function of the project specifications and the geometric properties). The list of attributes will be different for each type of building material object available, which, we stated earlier, could be over 360,000 different objects! The issue involved is to create one database that can extract from the geometric and material properties to provide the different views of performance and construction requirements for each different object and its attributes.

3. Information exchange level

The third technological issue involves attempting to take the designers' view or context of a project and translating it into the contractors' view or context. Specifications and paper drawings with standard symbols and representations are the exchange medium currently used, as was depicted in Exhibit 1. This proposal is all about raising the level of this translation with technology, and it must be decided at which level it should be performed. Using technology to exchange data at the design elements-building components level creates two issues. (Building components is the same as quantity survey.) First, it leaves the steps up to the estimate and construction plan levels to be performed by manual methods. Many will ask why these two translation steps are not automated.

The second issue with exchanging data at the design elements-building components level is that the 3D object model and database proposed is only good at presenting an object's geometric and material properties. The contractor, however, often needs to know or create the physical and sequential relationship between two objects. (This must be known to develop construction methodology such as the choice of phasing, necessary equipment, proper unit prices, etc.) Relating two objects to one another physically may be possible through relational features of the 3D model and database, but relating them sequentially is impossible without the domain knowledge of the contractor, which may be different for each bidding contractor. It must be determined at what level or levels translation can occur in order to minimize manual work yet provide the contractor with robust information.

4. Modeling objects versus attributes

In developing a 3D object model that is linked to a database of each object's attributes, an issue arises of how real world objects are modeled. All building materials are possible database objects in the sense of the word "object" when it is defined as "a tangible entity that exhibits some well-defined behavior" [Booch]. The issue is where to draw the line between modeled objects and attributes. For example, an interior wall may be made up of sheetrock, studs, screws, insulation, paint and more. It must be decided whether each of these objects should be modeled as individual "objects" on the CAD file, each with their own attributes listed in the database. An alternative is to model only the wall itself on the CAD file, and list the five or more materials as attributes in the linked database. This issue can become more complex, for example, if a door and frame in the wall are considered along with all the hardware and accessories that can go with a door. This definition between objects and attributes of objects will have to be drawn for thousands of building material combinations. If and when a definition can be drawn, it must still be determined how detailed the list of attributes for each type of material should be. For example, if "7' X 3' solid core birch door" is an attribute of the "door" object, should the area of finished veneer and the volume of core material be calculated as attributes since the door manufacturer will need to know this? The level of detail of objects and attributes needed to benefit all members of the contractor's team may require an impractical amount of effort to develop or to store electronically.

5. Standards organization to model the objects

Assuming that the author can provide suitable answers to the organizational issues raised in Section A and general solutions to the technological problems listed above, an issue arises about who will develop specific standards and models for each type of building assembly and material. After defining what are objects, many different trade organizations must define what are all of the relevant attributes for each material object. If each of the estimated 360,000 building materials has an average of five applications and five attributes for each application, this creates an enormous amount of standards to generate. In addition, the organizations must update and maintain these standards as new building materials and applications develop. Finally, one organization accepted by clients, designers, and contractors must coordinate and pull this effort together into one document, similar to Britain's Standard Method of Measurement, in order that the proposed system work on a universal basis for all designers and contractors. There is presently no one organization with this much support.

6. Size and exchange of data

As alluded to, there are technological details that must be resolved to generate the vast amount of material standards in electronic form, i.e., a database table needs to be created for the attributes of each potential application of every building material. One database of empty tables for 360,000 materials with 5 applications each, 5 attributes per application, and 20 characters to describe each attribute would take 180 megabytes of storage! It is a time consuming and expensive endeavor to store that much data. It must be stored on a large enough medium (like a computer's hard disk), yet still be easily reproducible and transferable (like a floppy disk). In addition, as described above, this data must be updated, maintained and redistributed on a continual basis. This may become a substantial cost that would have to be passed on to the users (designers) and that would add burden to the financial feasibility of the proposal.

The system proposed requires that each time a designer selects a material to go into the design that he or she complete the attribute columns in the table in the linked database. (This may actually be performed just once for each type of material in a project if it is used in the same fashion each time.) In the bidding process the 3D object model file and the linked external database must both be transmitted to all the bidding contractors and subcontractors wishing to take advantage of the system. The 3D object model for a 500,000 square foot building alone may require 250 megabytes of data! If it were constructed of 100,000 objects, with 5 attributes per object, and described by 20 characters per attribute, its external database would exceed 10 mega bytes. There is an added expense to reproduce and transmit this amount of electronic data to each bidder, and it may be highly noticeable if it must be done in addition to printed drawings and specifications.

7. Exchange standard

In addition to improving the estimating and procurement processes in the U.S. AEC industry, one of the broad goals of this thesis is to promote the creation and sharing of an electronic project object model and database between all parties involved in the design, construction and operation phases. To exchange this information via paper format only (not exactly possible for the object model, but isometric views can be printed) ignores the potential gains of CAD. However, paper format is still the only universally recognized format for exchange in the industry because it relies on standard symbols and the English language that any trained individual can read. Each of the present CAD developers (Autodesk, Intergraph, GDS, and IBM are the major developers, with many more minor developers) uses a different file format to express and store their project data. A government and industry attempt to institute an exchange standard, the Initial Graphics Exchange Specification (IGES), was updated as recently as 1992 but has been all but ignored by the CAD developers in their apparent attempt to hold on to individual market share. To take CAD data created on one system and convert it to another is possible to an extent through a translator program. However, it is not possible to translate an intelligent object model (only a series of 3D lines will translate) or its link to a database. What this means for the proposal at hand is that a contractor may have to purchase an additional CAD system every time the contractor wishes to bid on a project designed on a different system. Every contractor wishing to benefit from this proposal could conceivably be required to purchase four or more CAD systems and pay for the training, lost productivity, etc. This could render this proposal financially impractical.

This chapter has attempted to list the predominant problems and issues that impede the development and implementation of the proposed System, including organizational and technological issues. The next chapter, Chapter V, will describe the actual System proposed and the different components that designers and contractors will implement. Chapter VI will suggest solutions to the issues raised here in Chapter IV.

Chapter V. Description of System Proposed

This thesis relies on a new method of exchanging project information between designers and contractors at a much higher level than via graphic symbols on paper. To facilitate this exchange it is necessary that an information system, i.e., computer hardware and software, be proposed to generate the information and make the exchange. This chapter illustrates the proposed level of exchange and the tools to make it happen. The chapter goes on to describe how both designers and contractors will couple the system with their own existing procedures and tools to generate cost estimates.

A. Level of Information Exchange

In Chapter II "Rationale" we reviewed the transfer of information routine from architectural or design context all the way to construction plan. The only viable way to transfer this information under the separate designer/ contractor procurement method is to "reduce" design information to the lowest level, paper drawings and specifications. Upon receiving the exchanged drawings and specifications, contractors "interpret" their intent and develop a construction plan via an estimate and a structured list of building components. Contractors develop the building component list by converting symbols and text into geometric data and then structuring this data into numerical data so that estimating operations may be performed on it. See Exhibit 1. The British system is similar except for the fact that there is an additional exchange consisting of the structured list of building components, or quantity survey. This eliminates a vast portion of the interpretation process.

The intent of this thesis is to propose a system that better facilitates the exchange of project information between designer and contractor. Exhibit 4 provides the framework that allows the exchange of more structured information through electronic methods, yet still works within the existing distribution and separation of design and construction knowledge. On the designers' side, the process of refining and reducing design context from a designer's mind to a communicable format is practically unchanged. The difference is that under the proposed system designers will systematically keep track of their design elements in the CAD system and database via objects or groupings of objects, such as walls or rooms. Under present methods designers do not systematically keep track of design elements. Rather, they query the design analysis or drawings as needed to run calculations and perform more detailed design. By keeping track of objects and groupings of objects designers will be able to perform all types of calculations, including cost estimates, on the objects. The other difference in the proposed system on the designers' side is that the 3D object model will be able to carry and exchange much of the design information presently transmitted via the specifications. This will reduce the volume and increase the simplicity of the specifications.

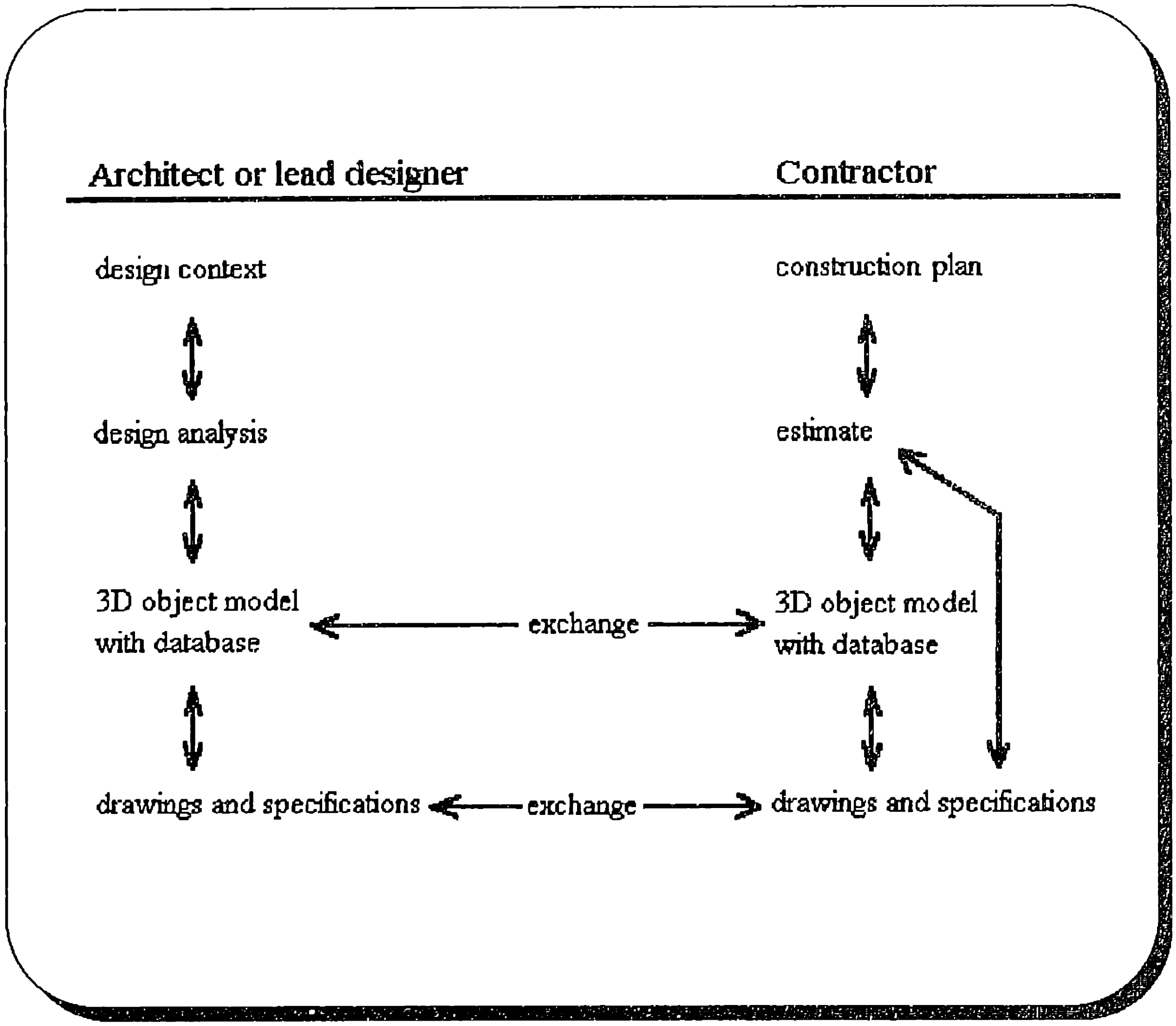
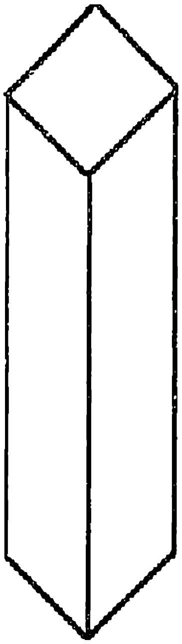


Exhibit 4

Proposed Designer-Contractor Communication

For contractors, the proposed system eliminates a procedure that is redundant with designers' conversion of design elements into graphic symbols, i.e., converting graphic symbols back into objects or building components. The exchanged database is simply a quantity survey of each object with all its attributes that the designer is capable of providing. Not all of an object's attributes can be provided by the designer. The system proposed allows for the addition of attributes by the contractor. Exhibit 5 gives an example breakdown of a concrete column's attributes that can be provided by the designer and those that must be provided by the contractor. Many of these two types of attributes are derived from information currently found in the specifications, reducing the need to reference between the drawings and specifications. It is important to see that the contractor must continue to use knowledge to interpret the drawings and specifications in order to complete an intelligent quantity survey.



Concrete Column

Attributes designers can provide	Attributes contractors must provide
SF of formed sides	type of side forms (handset, craneset?)
LF of chamferred edges	
LBS of vertical resteel	tie method (pretie, tie-in-place?)
LBS of horizontal resteel	
class & strength of concrete	
CY of concrete	placement method (crane, pump?)
SF of finished sides	

Exhibit 5

Example of Attributes of an Object

In Exhibit 4 the arrow from the drawings and specifications directly to the estimate is an important link that represents the application of knowledge about construction methodology and applicable unit prices. Contractors combine this knowledge with the quantity survey to generate an estimate. The System proposed in this thesis is very similar to the British system, except that in the proposed system a third party quantity surveyor is not needed. The exchange of quantity survey information can be performed electronically directly from the designer to the contractor. It is important to remember that in the British system the quantity survey, or Bill of Quantities, is not intended to be all the information required to prepare an estimate. British contractors must still thoroughly review the drawings and specifications to determine construction methodologies and analyze unit prices. The British system and the system proposed here eliminate the need to perform takeoff and reduce the requirement to interpret the finished product intended to be supplied.

B. Use of System by Designers

The proposed composite information system (CIS) will serve many benefits to designers as described in Chapter III. The benefits may be aggregated into two general categories: those that improve the entire construction procurement process, and those that improve the designer's ability to balance costs with effective designs. Regarding improving the entire construction procurement process, the last section described the levels of information exchange from designers to contractors, and this section will describe the electronic tools to facilitate such exchange. Regarding the ability to balance costs with effective designs, Chapter II "Rationale" pointed out designers' weakness in considering costs between the 30, 90, and sometimes 60% budget reviews. One of the features and benefits of the proposed CIS as described in Chapter III is the ability for the designer to have a more accurate and up to date estimate. This section describes the tools and procedures necessary for designers to take advantage of the system's potential. Exhibit 6 illustrates the procedural and conceptual schematic.

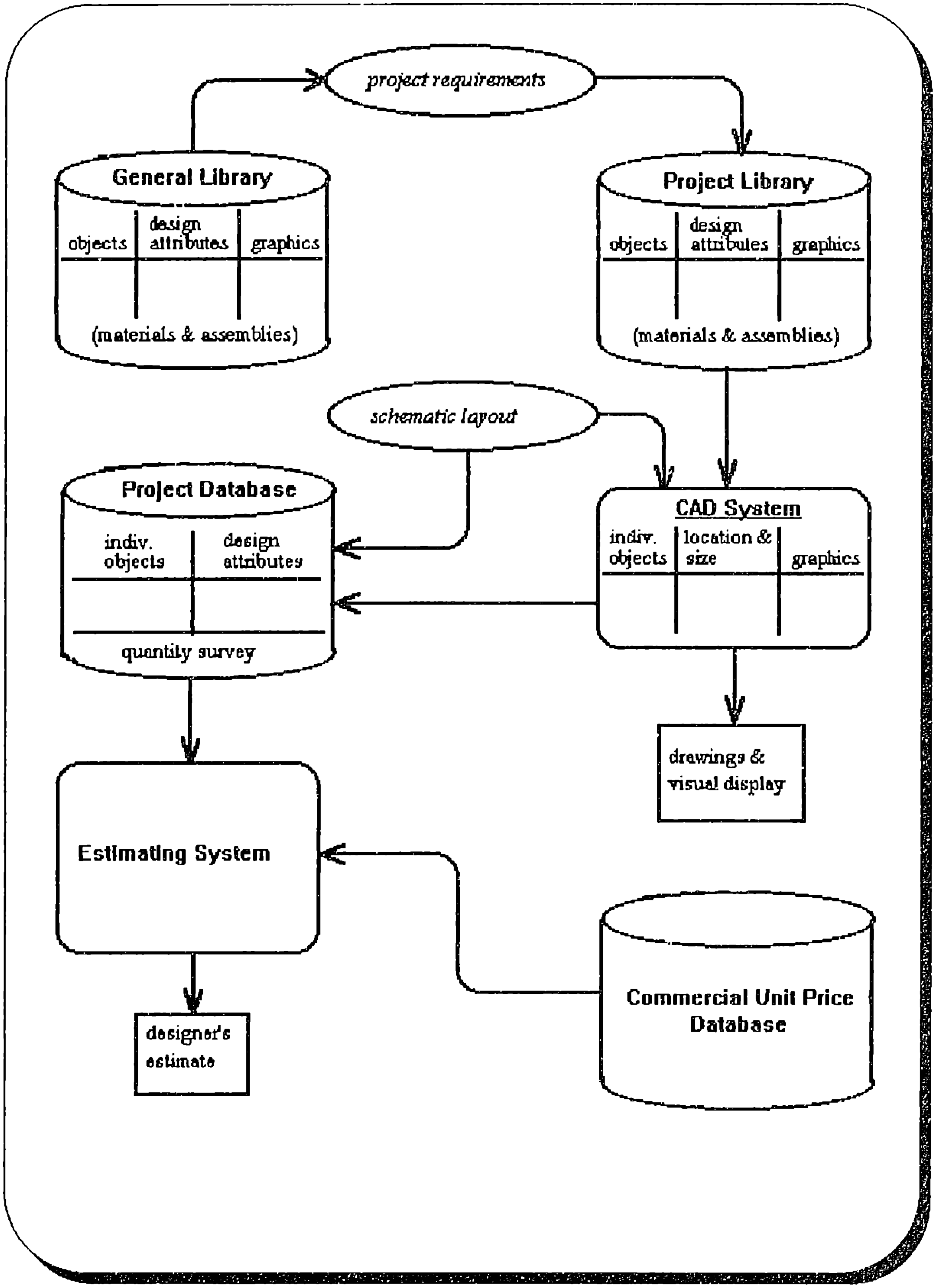


Exhibit 6

Schematic for Use of System by Designers

1. General Library

A database in its rudimentary form is a collection of information organized in some rational fashion. An electronic database, or a database management system (DBMS), is simply a database of information stored on an electronic medium and organized in one of basically four popular methods: hierarchical, network, relational, and object oriented. A General Library database as shown in Exhibit 6 is nothing new to design firms, although as proposed as a comprehensive DBMS it is new. Every design firm has a number of materials and material assemblies that they are qualified to design with, and although they may not keep an organized written record of them, they keep track of them in a sort of mental database. When designers read reports about new building materials and become comfortable with them, they add the materials to their design domain. Along with the list of materials, designers usually maintain specifications about the use of the materials. The specifications are all the attributes of a material that are involved in its construction and hence affect its performance. Within the past 20 years designers have begun to maintain these specifications on electronic word processing systems. Additionally, designers maintain graphic representations of these materials for use in expressing their designs onto drawings. Designers historically have kept tracings of materials and material assemblies that are easily reproduced and pasted onto design drawings. Now, however, designers are maintaining electronic copies of graphics that can be easily pulled into CAD files through the cut-and-paste method. Like the specifications, the paper and electronic graphics may be developed by the designer or received from a service or a vendor. The storage of all this information, however a designer maintains it, is a general library database that may be used on any project.

The General Library DBMS proposed in Exhibit 6 is a compilation of the information currently maintained by designers, but in one electronic system. The General Library will be more detailed than present methods in that it will be organized by objects, and not materials. This means that there will be an entry for each and every type of application for every building material. For example, the General Library will organize concrete by concrete beams, concrete columns, precast panels, etc. In an effort to expedite the design process, the General Library will maintain and organize building assemblies as objects, e.g., reinforced concrete beams, reinforced concrete columns. A more detailed example is a sheetrock wall that may contain sheetrock, studs, fasteners, insulation, finishing materials, paint, etc. Since many building products may be used individually or as part of another object, it is necessary that the Library include a listing for every conceivable manufactured building product. For example, reinforcing bars might not always be used in concrete assemblies. Thus many building objects will be modeled as objects as well as be listed as parts, or attributes, of other building objects or assemblies. It is not necessary to model objects any further than their typical building use. For example, cement need not be modeled as an object since it is never used alone, although it should be listed as an attribute for concrete objects and for masonry mortar.

Each object modeled will have a series of attributes that will describe its state of being. Its state of being may be its volume, weight, color or physical makeup, for example. The attributes included in the database must include those that a construction estimator would use to measure cost. Although it is outside the scope of this thesis, it would also be advantageous for each object modeled to have a series of attributes that describe its performance. The attributes of performance may be the object's ability to resist a force, to conduct heat, or to light a room, for example. The state of being and performance attributes are the design attributes shown in Exhibit 5. The value for the attributes will depend on an object's specific use in a project. The General Library data definition module must prompt for all potential attributes of an object.

Along with the design attributes, every object in the General Library will contain a graphic representation for the object. This field of the DBMS will be much more complex than present methods whereby designers store drawing files and simply cut, paste and magnify as necessary to fit the scale of the drawing at hand. Those files contain lines, points and arcs that make up a detail. The General Library must contain actual computer commands that create graphic output based on the size and chosen attributes of the specific use of the object: it must be able to create parametric models. For example, it must contain the commands to draw a 10 foot tall concrete column as well as a 15 foot tall column. Furthermore, since all building materials can be and most commonly are characterized as three dimensional objects, the graphic commands must operate in 3D. What has been described requires an object oriented database whose use is presently becoming practical and viable. For more information on object-oriented databases see [Gupta] and [Kim].

The development of a General Library that may be used universally by all designers in the AEC industry and provide the same output is the most difficult issue of this thesis proposal. Many building objects have the same attributes regardless of who the manufacturer is, and can be represented by government and private organization standards that are accepted by the AEC industry. Just as many building objects, however, are not represented by an accepted standard and may be manufactured with different attributes by different manufacturers. As noted in Chapter II, there could be as many as 360,000 different building objects, making the task of modeling each one a formidable task. Furthermore, the entries in the Library must be written in a computer format that is recognizable across the industry's vast array of CAD hardware and software platforms.

2. Project Requirements and Project Library

The *project requirements* noted in Exhibit 6 signifies a designer's thought and selection process of materials and material assemblies to be used in the specific project at hand. The number of different building object types used in a typical project will be a small fraction of those listed in the General Library. Pulling them into a Project Library DBMS makes future search and retrieval much more efficient. The Project Library also allows the designer to complete those attributes that will remain constant throughout the project. For example, a designer may determine that all concrete columns in a project will be constructed of 4000 psi concrete, and complete that selection just one time. Other attributes may still depend on an object's specific use in the project and will have to be completed as the object is placed into the design. Designers may use the Project Library to complete and name specific material assemblies, e.g., describing wall type "A" as having 1/2" sheetrock, 3-5/8" studs, and batt insulation. Completing these attributes has the same goal as developing the specifications does in current procedures. Finally, the Project

Library must receive and contain the graphic commands for each object selected. The development of the Project Library may continue throughout design as project requirements change or as new ones are uncovered. The Project Library will also be an object-oriented database.

3. Schematic Layout and CAD System

Once designers have selected materials to design with, they arrange them in a *schematic layout* based on the conceptual design. In the proposed System as seen in Exhibit 6, objects are retrieved from the Project Library and manipulated, or modeled, in the CAD System. The objects modeled may be single material objects or material assemblies. The System proposed is different from conventional CAD systems on the commercial market today in that it relies on and is organized by individual, identifiable 3D objects. Some present day systems, 2D and 3D, have the capability to group together a series of lines or surfaces and call the result an object. Most systems, however, simply create the commands that generate a number of lines or surfaces, the end result of which is a drawing, 2D or 3D. Each individual object modeled in the CAD System proposed will indicate its 3D location and size in the project, and will bring with it from the Project Library its graphic commands. In addition, objects may be identified by any number of identifiers including building system, trade, project area, etc.

An important feature of the CAD System is that it must have the ability to create 3D objects that are not available from the Project or General Library. Every project will encounter new objects that have never been modeled before, and the System must be able to draw them, identify them as individual objects, and then give them attributes. Most existing systems are capable of doing this. This ability allows designers to work with any range of shapes and then later label them as individual objects.

The CAD System will create a true model of a project in the sense that every line and surface drawn will be part of an identifiable object, except for notes and imaginary center lines. Like a physical model the CAD model will be capable of being viewed from any perspective. The System will be capable of producing views in the present formats recognized by industry, i.e., 2D plan views and elevations that are section cuts of the model. The views will be constructed on the computer monitor or on a printed drawing.

4. Project Database

The Project Database depicted in Exhibit 6 is the centerpiece of this thesis proposal in that it is the added medium for the exchange of project information from designer to contractor. It will be set up in blank form as a copy of the Project Library, but without the graphic commands. For this reason it may be considered a relational database. By copying the Project Library all the completed attributes that are not use-specific will transfer with the object types. For example, all the concrete columns may be set up with the attribute for "strength" equal to "4000 psi." The use-specific attributes, like the number of rebars, will transfer from the Project Library with the values left blank until the specific column is designed. The Project Database individual object entries will be created through a direct link with the CAD System to each individual object modeled. Designers will reference the *schematic layout* to complete objects' attributes based on their occurrence in the project, e.g., whether or not a concrete column is to receive a finish or not depends on if it is exposed to view. The individual objects will be organized by object type as well as by the identifiers created in the CAD System. The summation of the attributes by object types is the quantity survey, which may be sorted in as many ways as the objects were originally identified in the CAD System. The Conclusion will describe the many additional uses of the Project Database.

5. Commercial Unit Price Database

One of the benefits described previously of the proposed CIS is that designers will have the ability to run more accurate cost estimates at the later stages of design, defined earlier as design development and working drawings. At the earlier conceptual design (5%) stage designers will still be working with broad historical costs based on square footage or some other definable gauge. At the schematic design (30%) stage designers may be able to designate rooms or areas as entities and link to the Project Database. Designers can estimate and apply more defined square foot or other gauge unit prices on these areas, similar to current manual methods. These areas may later serve as groupings for the building objects inside them, but they are not to be confused with the entities from the General Library.

At design development (60%) designers will have selected most of their design objects (working drawings (90%) complete detailed dimensions, but add few objects) and will have a quantity survey of them in the Project Database. At this time estimating can change from a square foot or other gauge basis to a defined material object basis. To estimate project costs the designers need a database of unit prices to apply to the quantity survey of material objects. Since most do not have the knowledge or expertise to develop such an extensive number of unit prices to match all the potential object types, the designers must be able to purchase such a database on the commercial market. Commercial Unit Price Databases are presently for sale in the industry. They can be very informative and powerful in that they provide material, labor, burden, and overhead costs. They also provide different unit prices for different regions of the country where costs differ due to material costs and wage rates. What still needs to be developed, however, is a Commercial Unit Price Database that matches up with all the different object types modeled in the proposed System. To accurately estimate project costs there must be a unit price--not just for every object modeled--but for every attribute that has cost implications of every object modeled.

6. Estimating System

The Estimating System depicted in Exhibit 6 must be able to receive the quantity survey from the Project Database as input and match it with the appropriate unit price from the Commercial Unit Price Database. This requires nothing other than a simple spreadsheet program that can import data from two different databases. Most designers currently maintain such spreadsheets in their offices. The Estimating System multiplies quantities by unit prices and provides total and subtotal costs in as many different breakdowns as were identified when the objects were set up in the CAD System. Overhead costs are those costs that cannot be attributed to one group of building objects, but rather to the project as a whole. The Estimating System should be capable of applying overhead costs to the total project as well as to subtotals of individually identified areas.

The advantage of the proposed system for use by designers is that the designer may execute the Estimating System at any time after schematic design to receive an up-to-date total estimate or a subtotal estimate of a particular work area. For example, a structural engineer may execute an estimate of the structural skeleton of a building and inform the lead designer whether he or she is within budget or whether the building may need to be resized smaller. (The structural design is usually complete long before the mechanical, electrical or architectural designs.) The Estimating System may be used to run sensitivity on specific quantities, unit prices or overhead to see how a change in either may affect costs. Designers, if not already using an electronic estimating system, will find the Estimating System very simple and powerful to use.

C. Use of System by Contractors

This thesis proposal intends to maintain the existing responsibilities for the constructed facilities industry whereby design and construction are performed by separate parties. Hence there is no reason for contractors to use the part of the proposed System related to the designers' task of creating project designs. Yet contractors will use the same part of the proposed System as designers do to generate cost estimates in a manner very similar to the method proposed for designers. The contractors, however, will apply construction knowledge to the completed designs and quantity surveys to create estimates that are more detailed and accurate than the designers' estimates. Contractors will generate estimates in a process that is very similar to the existing procedures employed, the difference will be that the quantity survey has already been generated. They will engage their same thought processes, and will find that the necessary computer hardware and software is very similar to their existing estimating system and is easy to use. Exhibit 7 shows the proposed schematic for contractors' use of the System.

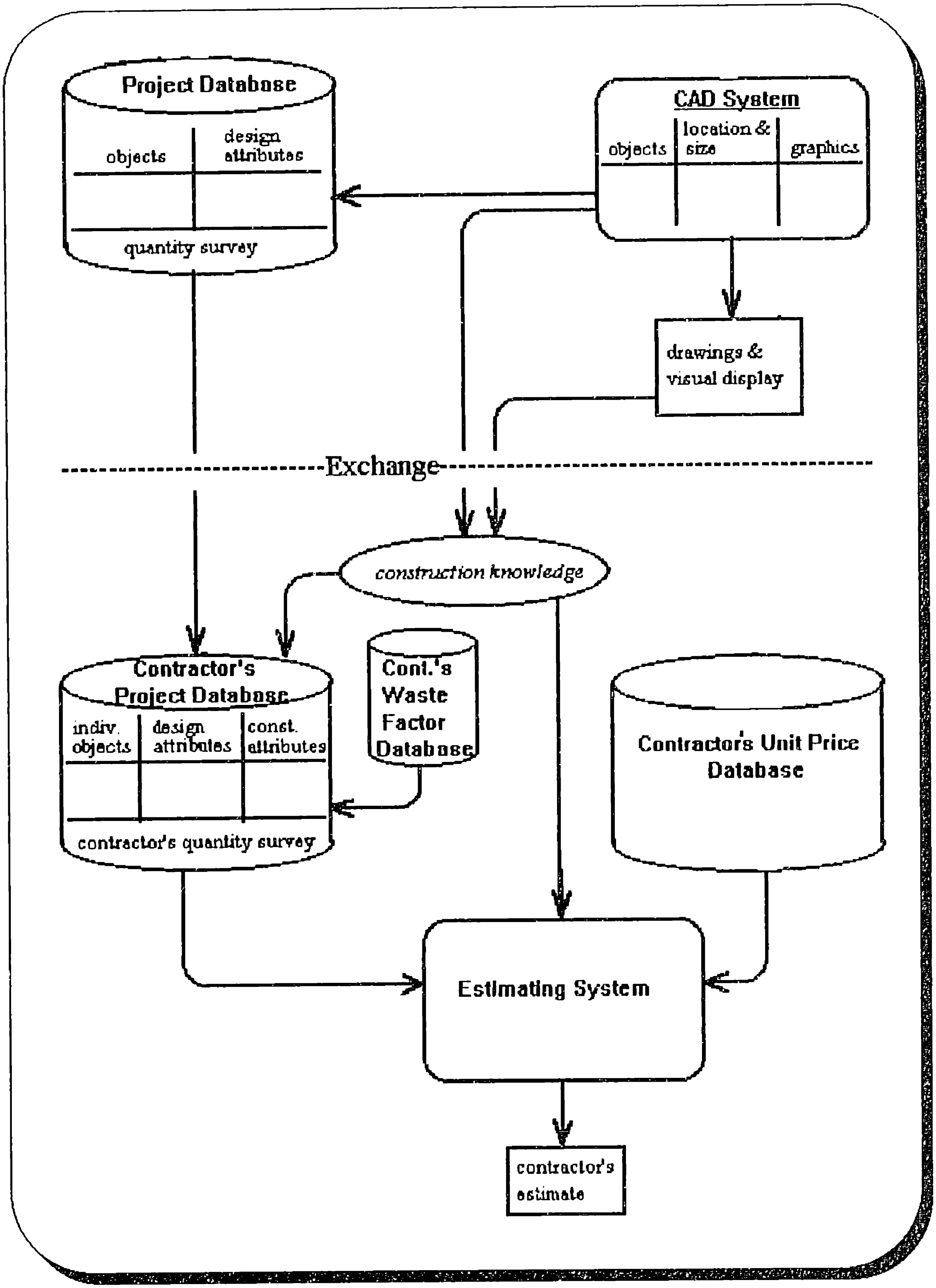


Exhibit 7

Schematic for Use of System by Contractors

1. Project Database, CAD System, and Drawings

Section B described how designers using the proposed composite information system would perform design on an object model CAD System that would link each object to a Project Database that creates and stores attributes about each object. As noted, the quantity survey is generated from the objects and their attributes. The CAD System should be capable of generating 3D views of the project from any perspective (current CAD systems have this capability). The proposed CAD system should also be capable of generating 2D elevation and plan drawings from section cuts, which is possible to an extent with current CAD systems. Although the quantity survey and drawings could both be printed out and exchanged to the contractor in paper format, this would overlook much of the potential of the CIS to improve the construction procurement process via electronic methods. For this reason it is proposed that contractors purchase the CAD System and Project Database software in order that they may receive the CAD and database files in electronic format via diskettes. This will allow them to load the files into their System and then query the data in any number of fashions. They might designate an object in the CAD System's visual display and instantly view its attributes in the Project Database; or, vice versa, designate an object in the Project Database and be prompted to its visual display and location in the CAD System. Paper drawings may still be printed and transferred to the contractor because they continue to provide a simple, however unstructured, exchange of project information. (Contract specifications, although not a focus of this thesis, may be partially reduced into attributes of objects in the Project Database. The balance of contract and specification information could and should be transferred electronically via simple word processing programs in addition to paper methods.) By reviewing the Project Database and CAD System files as shown in Exhibit 7 contractors will find that they are given a whole new power to match the quantity survey with the visual representation and extract additional information helpful for preparing an accurate estimate.

2. Construction Knowledge, Contractor's Waste Factor Database, and Contractor's Project Database

The Project Database as depicted in Exhibits 6 and 7 contains a quantity survey of all the required in-place materials in the completed project to meet the minimum requirements of the design. Some of the materials are the modeled objects, while others are attributes of the modeled objects. The quantity survey is a measure of some combination of the materials' occurrences, lengths, areas, volumes or weights. The measures that should be included in the Project Database are those that make economic sense and that have physical in-place qualities. An in-place quality can be defined as a quality that can be physically measured after construction, e.g., cubic yards of concrete in concrete columns. However, there are a number of attribute measures as exemplified in Exhibit 5 that do not make economic sense to every party involved or do not have physical in-place qualities. They are attributes that indicate "how to" and not "what to" construct. Hence they are the domain of the contractors and must be determined by them as necessary to make the estimate as detailed and accurate as desired. They may vary from use to use within a project depending on certain circumstances. Ultimately the construction attributes are used to create a more refined match between quantities and unit prices.

To define these "construction attributes" a construction firm must study a project's design and employ its *construction knowledge* to know which materials need additional modeling. Most materials will not require additional modeling because their use does not vary from location to location in the design. Contractors will need to review some materials by location, however, so that they might select construction attributes based on the material's specific use and relationship to other materials and objects. For this reason the Project Database that the contractor receives must be capable of adding data attributes as necessary. The contractor will open the Project Database while reviewing the design drawings and create the additional attributes. For example, a contractor might query the Project Database for all the concrete columns, and then while reviewing their location in the design designate each as requiring handset or craneset forms (see Exhibit 5). These are terms that make little or no sense to designers. It may be that all the project's columns can be craneset and that one command to the Project Database will designate them all as such. Section 3 will describe how a different unit price will be applied to the craneset columns as to the handset columns.

The quantity survey included in the exchanged Project Database is a survey of the minimum quantities of in-place materials required to complete the project design. It does not, however, give any indication to the amount of materials that may be wasted during construction due to loss, breakage, spillage or sectioning smaller pieces from the standard order sizes. Most contractors maintain a formal or informal database of applicable waste factors for every material that is not ordered in prefabricated condition and subject to waste. This is another area for contractor differentiation since it requires knowledge and experience to accurately select the minimal waste factors. For this reason contractors must be able to apply waste factors to the quantity survey. Maintaining them in a Contractor's Waste Factor Database with material identifiers is an efficient method for matching them up with the applicable materials. The Waste Factor Database should be capable of being adjusted on an ad hoc project basis to compensate for specific conditions. It may be a simple relational database based on the same format as the other proposed databases. The unit prices in commercial unit price databases used by designers typically include a cost factor for waste. Most contractors, however, appreciate the additional control of tracking waste factors separately so that they can use the resulting net quantities for ordering materials.

The end result to the Project Database after the addition of the construction attributes and the waste factors is the "contractor's quantity survey." On a single project it will be different from contractor to contractor, hence creating differentiation. Yet it will be based on the same shared "quantity survey" created by the Project Database.

3. Contractor's Unit Price Database

Every contractor maintains some form of a database of construction costs, usually in unit price format. In contrast to designers who may only be interested and capable of using one total unit price, contractors want the level of detail and accuracy found by tracking material, labor and equipment unit prices separately. Some contractors just have a series of written and mental records from their experience or from a published source of what costs have been historically, and they apply these to the quantity survey. Most, however, maintain this database on electronic medium. Contractors will often purchase an electronic unit price database from a publisher of construction information, and then augment it with some of their own experience. The Contractor's Unit Price Database proposed may be from a published source, but most contractors will want to verify and "tweak" the unit prices. This will provide contractors a source of differentiation and competitive advantage.

The Contractor's Unit Price Database must be capable of adjustment in material, labor, and equipment unit prices by individual contractors. This is necessary for each contractor's differentiation and for adjustments in costs due to economic regions or conditions. The Unit Price Database should also contain the same identifiers that mark the materials in the Project Database in order to match the materials with the corresponding unit prices. It is important to note that the framework for the Contractor's Unit Price Database may need to be developed and mass marketed by a software service, but that the unit price content is the domain of the individual contractor and should be protected to maintain differentiation.

4. Estimating System

The proposed Estimating System shown in Exhibit 7 is very similar to existing estimating systems that many contractors currently employ, except that it does not create the quantity survey. The Estimating System operates by extracting the contractor's quantity survey from the Contractor's Project Database. It then locates and matches the applicable unit prices from the Contractor's Unit Price Database. At that time contractors may make adjustments to any of the quantities or unit prices in order to suit the conditions of the project. Finally, contractors may employ *construction knowledge* in the Estimating

System to estimate all of a project's managerial and equipment overhead and any temporary construction. Most contractors prefer to add the subtotal of their overhead and temporary construction to their subtotal of material, labor and equipment costs, and then apply percentage factors for costs and fees that are a function of total project cost. As can be seen, the Estimating System is really just a simple spreadsheet. When executed it calculates the "contractor's estimate."

The Estimating System, like all the other components of the proposed System, must be capable of adapting to special situations. Almost every project will include objects in the quantity survey that have never been used before and are not included in the Contractor's Unit Price Database. The Estimating System must be capable of integrating with manual methods.

The next chapter will suggest solutions to the issues raised in Chapter IV based on the description of the System proposed in this chapter.

Chapter VI. Responses to Problems and Issues

Chapter IV pointed out a list of issues obstructing the development of a full scale commercially available CAD system that generates and shares a detailed quantity survey. The issues, or problems, dealt with organizational resistance from both designers and contractors who see this thesis proposal as threatening their accustomed mode of operation. Designers and contractors are also pessimistic that the proposed system will be useful or cost effective. This chapter will attempt to provide responses to these organizational and technological issues. These responses are organized in direct correlation to the issues listed in Chapter IV.

A. Organizational Issues

The solutions to the organizational issues revolve around reassigning project responsibilities without disrupting the distribution of design and construction knowledge. The solutions also involve developing new protocols and legal guidelines.

1. Issues involving designers

This section proposes that designers reassume certain responsibilities that reinforce their leadership roles in projects. A cost to benefit ratio is provided.

a. added responsibility

Designers will be taking on additional work and responsibility to operate the proposed 3D CAD System and develop the Project Database. Costs for training currently employed designers to operate the 3D systems in lieu of existing 2D systems will need to be factored into the cost-benefit equation. Since designers are taught to envision their conceptual designs in three dimensions it is conceivable that design students will become adept with 3D CAD systems during their education as they are becoming adept with 2D CAD systems currently. It is important to note that by operating the 3D CAD System and Project Database no new work is being added to the overall design and construction process. Although it is difficult to comprehend, the development of 3D models and quantity surveys is the structuring of information that contractors must perform anyway, either through visualization, preparation of detailed shop drawings, or takeoff. (Designers currently visualize their designs in 3D and then deconstruct this information into 2D line drawings.) This thesis proposal simply readjusts the responsibility breakdowns for structuring project information, and designers should clearly be compensated for their additional work. Additionally, designers will find that the General Library may make their task of pulling together graphic and written information much easier. After productivity improvements are gained with experience, designers should become comfortable with the use of the system.

It is important to take a closer look at the shift in responsibility for preparing detailed designs. In the past few decades responsibility for preparing detailed designs, e.g., preparing connection details for structural steel members or coordination drawings for electrical conduit, has shifted from designer to contractor. Recent judgments in the Kansas City Hyatt collapse lawsuits confirmed the responsibility of designers to check and ensure that building code requirements are met, but contractors continue to prepare many details. Contractors need these details, or at least a general understanding of what they will be like, at bid time to prepare an accurate quantity survey. It is possible that in the proposed 3D object model the details could reside as attributes of the materials in question. Although this thesis proposal could be implemented with as much or little detail being provided to contractors as desired, the level of detail will determine the amount of reduction in takeoff and interpretation by contractors. The author proposes again that the added work for designers to prepare these details does not add any new work to the overall design and construction process; it just rearranges the responsibilities. Designers may not welcome this as they attempt to shed responsibility and focus on their expertise. However, one prominent architect proposes that by creating and sharing detailed 3D object models, architects "can remain in control of the process while tapping others' expertise when we need it," and "can return architects to their leadership role" [Novitski August 1992]. It may be assumed that all types of designers, like engineers, can return to a leadership position in their respective fields and trades. Leadership roles have many advantages including commanding higher fees, but at the expense of others. The author considers this problem of convincing designers to assume added responsibilities to be one of the most considerable issues of this thesis proposal. Section 2a and 2c of this chapter will look at the other side of the issue and discuss the possibilities for contractors to remain in control of their expertise and domain.

b. added liability

Chapter IV pointed out that designers are extremely reluctant to generate quantity survey information due to the fact that they may become liable for its accuracy and completeness. Designers inevitably make omissions in designs, and the payment for the extra construction work when discovered is a volatile issue between clients and designers.

The omissions will become clearly visible during construction with a shared quantity survey. Designers fear that clients will force them to pay for the cost of the omissions. The suggested solution is for both parties to comprehend and appreciate the capabilities of 3D CAD to improve the quality of contract documents by creating better checks for interferences, errors, and omissions. Also, clients and designers must see the power of the Project Database to create a quantity survey as a way to check for omissions. If designers make the concerted effort to improve the quality of contract documents, the clients should be willing to come to the bargaining table. Clients will have to understand that implementing the proposed system is not a fix-all solution to the problems of construction procurement; change orders will need still need to be written for items that were omitted and not included in the bid price. Clients must be willing to understand the difficulties and intricacies of completing designs and be willing to pay for these omitted items. Designers in return must commit themselves to preparing high quality and complete designs. A higher level of mutual trust between clients and designers and a limit in designers' liability is required before designers will commit to creating and sharing quantity survey information.

c. will require designers to think like contractors

To properly develop the Project Database designers will need to consider more about building materials' cost and constructibility than they currently do. However, designers will not be required to develop the attributes of objects and materials if contractors and trade associations are involved in the development of the General Library. Designers, contractors and material fabricators together must develop the attributes of each building material and object in order that the attributes express the information that each party needs to know about the material or object. (See Section B5 of this chapter for the strategy to develop the General Library.) This is in effect building constructibility knowledge into the General Library for designers to make use of.

The specialization into design and construction last century and then later into sub specializations of each is no doubt responsible for the great productivity gains described in Chapter II, Section A [Cremeans]. But to tightly hold the information and knowledge domains of each profession and to completely separate design and construction is to lose much of the potential of collaboration. A common General Library of objects and attributes and a Project Database have the potential to allow designers and contractors to understand the other's domain better without distracting them from their core competencies.

d. changing from graphic primitives to objects

To get designers out of the 2D line drawing mentality and into considering their design drawings as representations of 3D objects is a difficult task that will not be accomplished overnight. As noted in Chapter III, forcing the users in a CIS to adopt new means and methods of working is a good way to create dissension and even sabotage in the ranks. A better way to implement the CIS CAD system proposed is to implement it gradually over time. Designers will begin to realize that their original design conception was in 3D objects but that convention and standard practice has forced them to reduce their concepts into series of 2D lines. Additionally, the system proposed should not be a rigid system whereby designers may only draw 3D objects onto the files. Rather, the system should allow designers to make sketches on the screen and then later define them as 3D objects. This will allow designers to express their thoughts in a conventional fashion, yet label them with attribute information. Finally, the incorrect notion that the object-oriented design is associated with flat and square shapes, and does not lend itself to details and curvatures, must be overcome. Designers will become comfortable with an object model system, but not overnight.

An added and unexpected benefit of 3D object models for designers will be their ability to model and view complex 3D shapes and curvatures. 2D drawings are an insufficient mechanism for designing and visioning 3D curvatures. 2D drawings of these curvatures make the task of designers and architects more difficult, to say the least. 3D CAD object models, using developments from the aerospace industry, are revising the way designers create and share their designs. An example may be found in [Novitski August 1992].

e. cost to benefit ratio

Based on a review of the System's schematic for use by designers in Exhibit 6, the different costs to designers can be defined. However, only a rough estimate of these costs may be performed at this time. This section will use an example of a hypothetical design firm that designs $50 million worth of construction value a year. The design firm will be required to purchase the General Library as well as revisions on a regular basis. If the strategies described in Sections B5 and B6 of this chapter are followed, then the design firm's cost to purchase and maintain the General Library may be minimal (assume $4000 a year), but this is only an estimate. The second additional cost will be to purchase database software for the Project Library and Project Database. System implementors will determine whether these will require the recently invented object-oriented databases (OODB), or the more developed relational databases (RDB). Commercially available OODBs are still relatively undeveloped and expensive: a package for a network of computers may cost $20,000. RDBs, however, have gone through user development and economies of scale, and are much cheaper, giving hope that OODBs will drop in price. One copy of a DB program will be adequate for an entire design office of moderate size. The design firm will need to purchase new or upgraded object model CAD software, as well as more powerful machines to run the software. If these costs are double the current costs of CAD software and hardware, they may be an additional $5000 each, or $10,000 per CAD seat. We will assume eight (8) CAD seats are necessary for the hypothetical design firm here. As described in Chapter V, the Estimating System required is little more than a sophisticated spreadsheet, and could probably be purchased for less than a few thousand dollars (assume $2000). A Commercial Unit Price Database currently sells on the market for $ 175 [Means], but it can be extrapolated that to purchase a Unit Price Database organized by the General Library object listing might cost $ 2000. The total of these one-time costs might be less than $108,000, and depreciating them over a five year period yields a cost of less than $22,000 per year. (The net present value of money is not considered because it does not appear to be a major factor.) This $22,000 per year total hardware and software cost for an average sized design firm must be considered in conjunction with the operation costs and the benefits.

The cost to train a designer on all the components of the proposed System is a one time cost that is difficult to estimate, and will include costs of reduced productivity while the designers get up to speed. The costs to operate all the components of the proposed System are also difficult to estimate because the procedures overlap with existing design, specification writing, and estimating procedures. It may be useful to look back at these costs after the benefits are defined.

The tangible benefits to designers are the added fees they may request from the client for generating and sharing the quantity survey. An estimate might be made that this is worth an additional 0.1% of construction value, which, for a design firm that oversees $50 million of construction a year, would equal $50,000 a year in additional fees. The less tangible benefits include 1) the additional value that may be designed into a project as a result of having more accurate preliminary cost estimates, and 2) the general understanding that develops between client, designer and contractor from having a quantity survey that is shared among all parties. To place a definite value on this is impossible.

The intent of this section is not to define the costs to designers of the proposed System, but to suggest a scenario for the distribution of costs that may be used when the System is further researched and the costs refined. One can see that for an average design firm that designs $50 million of construction value a year would have a surplus of $28,000 a year ($100,000 additional revenues - $22,000 hardware and software costs). The firm could spend the surplus on the additional cost of training on and operating the object model system before costs would be in excess of benefits. In addition, the intangible benefits to designers described above need to be considered. Although the costs are expensive and the estimates provided herein are rough, it is possible to see that the proposal provides a viable means for designers to cost effectively increase their level of service.

The Conclusion of this thesis will include a final cost to benefit ratio for the entire AEC industry, or rather the net benefit to clients. The 0.1% additional fees for designers will be used as a cost to clients.

f. quantity survey information in the specifications

Critics are correct in stating that under the current convention of design documentation much of the information required for the quantity survey resides in the specifications. However, the design attributes in the proposed Project Library are actually all the information about an object or a material that the design requires. That is, the attributes of a material or material assembly will describe the exact classes of materials and any accessory items that go with them, e.g., fasteners. In other words, it describes "what" is to be provided. Therefore if the Project Library is developed properly there will be no need to reference specifications during takeoff. The Project Library will not, however, replace the parts of the specifications used in conventional methods to describe "how" materials are to be provided and installed. This means contractors will still need to read the specifications when planning construction methods and refining unit prices.

Already there is a movement under way to better integrate drawing and specification information on paper format. Organizers from the American Institute of Architects (AIA) have developed a program named ConDoc® for the Construction

Documentation System. The AIA realized that under the existing system, often items were called for on the drawings but not defined in the specifications, and vice versa. They also realized that most designers wanted to use their own drawing format, making the job of the estimator, specifications writer, contractor and owner more difficult when trying to find information on the drawings. ConDoc® provides a uniform format for drawing representation (similar to what AIA's MASTERFORMAT® did for specification standardization) and provides a standard note designator to all materials on the drawings that relates them directly to the appropriate specification. One powerful government supporter sees "ConDoc® as a valuable tool in producing standard unit costs leading to a fully automated cost engineering system" [Rutherford]. This sounds like the first steps of a standardized format for the Commercial Unit Price Database proposed in Chapter V. Integration and standardization of drawing and specification information are an important step towards achieving the goals of this thesis, namely creating a standard representation and exchange mechanism for the sharing of CAD object models and their quantity surveys.

g. electronic data is not legally binding

The Project Databases and CAD files should be transferred electronically from designers to contractors in order to get the most advantage out of the proposed System. In essence the files will become contract documents. A method must be developed that allows this information to be transferred on a medium that cannot be altered in order that multiple copies will always contain the exact same information for consistency and legal reasons. Read only memory (ROM) discs are a first step in that they do not allow any information to be written onto them after they have been sealed. However, ROM discs can be copied onto other discs and then manipulated. Also, the many revisions that usually occur to a project's design during construction will need to be added to the project disc. To keep track of the multiple revisions during a project, identifying labels can be placed on the electronic files. These labels are a count of the number of computer operations that designers have performed on that file, and may number in the billions. It is virtually impossible to clone a file with the exact same number of operations. Also, if the original file is modified in any way a change in the number of operations will show up. The original design file may have one identifying label, and each successive revision may have its own label. It will take some getting used to, but electronic files can be maintained with integrity. An alternative is to specify that the paper copy, not the disc copy, is the contract document.

h. contract terms for shared Project Database

Since the separation of the design and contracting responsibilities over 100 years ago, the construction industry has had to develop many new contractual agreements for the variety of responsibility breakdowns, including design-build, construction management, and unit price work, to name a few. It will be necessary to create new contract terms that provide for the designer generating and sharing the Project Database, due to the fact that it provides the quantity survey to the contractor. It is suggested that there be two types of contracts, the first covering an agreement where the Project Database is shared for information purposes only. This would mean that the contractor is still responsible for determining and guaranteeing quantities, but could use the Project Database as a check against its own takeoff. The second type of contract could allow the quantity survey generated by the Project Database to serve as a Bill of Quantities for the maximum in-place quantities required by the project. When a change in design occurs or when a dispute arises over the requirements of the contract documents, the Bill of Quantities could be referenced to determine the original requirements of the documents. This might actually make the change order process much less ambiguous and simpler to manage than methods currently practiced. Unit prices for the many different materials and objects that are affected could be negotiated as they arise. Contractors will be concerned that the contract terms clearly inform them of the significance of the Project Database, i.e., whether they can rely on it for all the quantity survey information they need to estimate and complete a project. Designers will be concerned that their own contract terms limit their liability from omissions in the quantity survey, and that the insurance industry will be willing to insure them for the added liability they inevitably acquire. One architect who is a proponent of sharing electronic project models said that "Given the potential benefits, if we can make this work, I don't think the legal and insurance systems will have any choice but to change" [Novitski, August 1992].

2. Issues Involving Contractors

This section suggests that contractors will find that this thesis proposal matches many contractors' efforts to reduce risk and focus on developing core competencies.

a. reduction in responsibility and fees

The proposal to provide all bidding contractors with a Project Database that contains a quantity survey no doubt reduces the responsibility of contractors to contribute to the project. To some contractors this may be undesirable, since there will be a corresponding reduction in fees. Most contractors, however, are risk averse and look for ways to concentrate on their core competencies only. This is the reason most contractors subcontract all work in which they are not especially competent. Many general contractors (GCs) in the past decade have shifted to construction management (CM) arrangements where contracts are written between the client and subcontractors and hence risk is shifted upstream to the client and downstream to subcontractors. Both approaches reduce the fees that may be expected, often by two or more percentage points of construction value. For example, on a specific project a contractor might include in its bid a 5% or 6% fee if it is for a GC type contract. The same contractor on the same project might bid 3% or 4% if it is for a CM type contract. Risk averse contractors will not have trouble adopting to contract situations where designers create the quantity survey. It is important to understand that contractors' fees in the form of percent markups are proposed to go down to pay for the costs of development and use of the system by designers. However, contractors' costs of doing business will go down also. Contractors should not consider this proposal as a reduction in their profitability.

b. loss of differentiation and competitive advantage

Sharing the Project Database with all bidding contractors would clearly negate any differentiation between contractors attempting to determine in-place quantities. As can be ascertained from Chapter 5, Section C, there are many more steps beyond the takeoff of in-place quantities required to complete a cost estimate, including determining contractor-specific material attributes, waste factors, unit prices, overhead, and construction sequencing. Takeoff is the listing and summation of all materials and their attributes relevant to cost. Often contractors can define and list all the materials but are not competent about a particular material and do not know the attributes relevant to cost to take off. For example, a contractor with no experience in concrete columns may not know that specified chamfered corners are a significant cost attribute that need to be measured.

A more common occurrence is for contractors to make an error in defining and listing the materials and objects. There is an old joke that under competitive bidding procurement the only way to be the low bidder is to make a mistake. Under current procurement methods there are really no competitive advantages in performing quantity takeoffs, rather there are competitive disadvantages when a contractor makes an error. Providing and sharing a quantity survey to bidding contractors will emphasize the need for differentiation and competitive advantage in the many steps of calculating a cost estimate after the quantity survey is developed.

c. role of general contractor may diminish

This issue expresses the feeling of a number of general contractors who see the proposed Project Database as a communication means directly between designers and subcontractors or fabricators, effectively bypassing general contractors. The example cited was about an architect who electronically sent 3D fabrication information to a fabricator, bypassing the general contractor. It is true that as information becomes easier to communicate, the role of the general contractor as the conduit for information and as the coordinator will diminish. It is important to understand that coordination does not add recognizable value to a project as design documentation or production does. For this reason, successful general contractors will develop or maintain and promote a core competency that they may use as differentiation. This competency may be to provide some form of design and build, or it may be to specialize in a specific area of construction production. Either way, coordination by itself is a shrinking no-man's land that computer tools like the Project Database will begin to handle more and more of in the next few decades. In the meantime, though, there is much need for leadership by general contractors (who are generally financially more capable than subcontractors) in promoting and instructing the use of the CAD System and Project Database. General contractors who purchase and promote the system earliest will be able to establish a leadership role and may be able to get subcontractors to come to them to pay for time on their computer systems and get instruction. The more competitive general and sub contractors will seek out opportunities and position themselves for changes in the industry.

d. cost to benefit ratio

The cost to benefit ratio for contractors using the proposed System is much simpler to consider than that for designers. It is still just a scenario for a distribution of costs and benefits, but the variables are fewer. The thesis proposes that the System be a series of off-the-shelf components that any design or contracting firm could purchase and implement without a staff of computer programmers. Contractors' costs to operate the System are not calculated in the ratio because they are costs that contractors currently spend while calculating <u>estimates</u>. It is important to remember that the thesis intends to eliminate or reduce <u>takeoff</u> costs only.

Most contractors, who currently do not operate CAD systems, will be faced with the cost of purchasing from scratch the object model CAD software as well as hardware to run it. Estimates for these costs are $10,000 each, or $20,000 per CAD seat. An example of the hypothetical contractor that bids $300,000,000 of construction a year is used. It is estimated that this contractor would require four (4) CAD seats, costing a total of $80,000. Other costs would include a database program to copy the Project Database into, which was estimated earlier to cost a maximum of $20,000. The same simple spreadsheet as proposed for designers could be used by contractors as an Estimating System. However, most contractors enjoy additional capabilities of the currently used systems and would want to reconfigure it to read from the Project Database, which can be estimated to cost $10,000. The same would be true to redevelop the contractor's Unit Price Database in the fashion of the General Library object listing, which can be assumed to also cost $10,000. The total of these one-time costs is $120,000. Depreciating these costs over a five year period, the yearly cost to the contractor described would be $24,000. This scenario does not divide any of the CAD system costs into the other tasks that might use and benefit from the system, like marketing, shop drawing preparation, or as-built preparation.

Chapter III, Section A1 calculated a savings, or benefit, from gross reduced takeoff costs of $75,000 per year for the same general contractor that bids $300,000,000 of construction a year. This number might be a lot larger for a contractor that takes off more of its estimates and subcontracts less of its work. The $51,000 net savings ($75,000 - $24,000) shown here is again not intended to define the exact benefit to a contractor that adopts the proposed System. Rather it is intended to suggest a scenario for the distribution of costs and benefits that may be used when the System is further researched and the costs refined. However, it can be seen that the proposal for contractors may be a financially viable alternative to quantity surveying based on the assumptions used.

The $51,000 net annual savings to the one contractor is 68% of that contractor's gross annual savings ($51,000/ $75,000). From Exhibit 2 we know that there is a vast duplication of takeoff effort among contractors bidding for work in the U.S. Extrapolating this 68% for all the contractors and subcontractors that bid on construction work gives a net savings in takeoff costs to the industry of 0.32% of construction value (68% x 0.47% gross savings from Exhibit 2). The Conclusion will summarize and calculate the cost to benefit ratio for U.S. construction clients, using 0.32% as a benefit for takeoff cost savings. Chapter III, Section B1 mentioned a 0.50% savings in contractors' fee reductions in exchange for reductions in risk. This 0.50% will also be used as a benefit from contractors using the proposed System. In total, contractors are expected to reduce their costs to clients by 0.82% of construction value.

c. sophistication of technology

It is only natural that contractors have been slow and somewhat reluctant to adopt CAD systems in their offices because it has had little use for firms not performing design. Now, however, some designers are beginning to offer their respective contractors CAD files of projects, and the contractors are finding uses for the files when they purchase a CAD system. These contractors are using CAD for preparing proposals, reviewing site and sequence planning, creating schedules, preparing shop and coordination drawings, and completing as-built drawings. Software vendors are even beginning to create applications that allow estimating programs to perform takeoffs from CAD drawings displayed on the screen.

There is a quiet revolution under way bringing CAD into contractors' offices. CAD has never been too sophisticated for contractors to use, but it has been arduous and not cost effective. Fortunately for contractors, over the years designers have debugged CAD and demanded user friendly graphical user interfaces (GUIs), similarly to how contractors have improved estimating and scheduling programs. To make the transition into the use of CAD and database software smoother for contractors, universities should begin to teach CAD and database skills to prospective construction employees. This should include architecture, engineering and building science students. Contractors should begin to look for prospective employees with this education, and should support training for current personnel. If they have not already, contractors should begin experimenting with CAD. There are a number of CAD implementation guidelines that successful users have developed (see [Kappelmann]). Most CAD vendors offer frequent CAD user training courses all over the country. Contractors that attempt to jump onto the CAD revolution and purchase the proposed CAD System and Project Database (when it is developed) without careful planning and training, will find CAD sophisticated and their investment unprofitable.

f. trust in the quantity survey

If the quantity survey in the shared Project Database is designated as a binding Bill of Quantities, contractors' trust in it will not be an issue because they will be able to recover errors in change orders. If it is not a binding Bill of Quantities, skeptical contractors may learn to trust the quantity surveys over a series of projects where they perform a manual takeoff and compare it to the Project Database's quantity survey. A more scientific way of becoming comfortable with the quantity survey is for the estimator to take advantage of the electronic link between the CAD System and the Project Database and select random objects in the CAD System. Contractors may then review all the takeoff attributes in the Project Database for completeness and accuracy. Chapter IV pointed out that even if contractors trust the quantity survey for accuracy, some believe they may not like its method of representing objects and materials or its format. The representation drawback should be eliminated if contractors understand that the Project Database is designed to represent every object and material in as much detail as possible. They will find that, if anything, the objects and materials are represented in more detail than they are used to. This additional attribute information will be welcomed by sophisticated contractors who can apply unit prices to all the levels of detail. For example, estimating a concrete column by all the detailed attributes listed in Exhibit 5, and not just by the cubic yards of concrete, benefits the contractor that knows unit prices for each of the attributes. Contractors unfamiliar with the attributes may learn to take advantage of this level of detail, or price the column by the cubic yards of concrete only, and not apply a unit price to the other attributes.

The author does not perceive the reporting format of the quantity survey to be an issue due to the fact that a relational database can be adjusted to sort and present its data in any format desired. Either the contractor or, more likely, the Estimating System developer, may use the Structured Query Language (SQL) to set up commands to query the Project Database to present its data in the format desired. In conclusion, contractors will have to make some form of adjustment from their current estimating methods to take advantage of the proposed System, but it will not be radical adjustment.

B. Technological Issues

As noted in the introduction to Technological Issues in Chapter IV, computer hardware will not be a hindrance to the proposed System. Computer and semiconductor manufacturers continue to develop faster and faster microprocessor speeds that will easily handle the volume of object and attribute data proposed. As manufacturers travel down the learning curve and economies of scale are created, the price of microprocessors continues to drop dramatically. The same holds true for all the other components of a computer. The difference between personal computers and mainframes, miniframes or workstations is becoming blurred as PCs' speeds and networking abilities improve and rival their counterparts. This will make it conceivable to operate the proposed System on low-cost and easy to use PCs. Some of the other technological issues, however, will require more than sheer technological improvements; they will require in-depth work by a joint effort of clients, designers, contractors and CAD developers in order to develop standards and promote them.

1. 3D versus 2D

Designers and contractors alike should understand that there is a big difference in operating a 2D CAD system versus a 3D CAD system, much less a 3D object model CAD system. Besides the relatively high cost of purchasing additional software and training for 3D systems, most industry observers agree that it costs more time and effort to create a design in 3D [Atkin 1986, Mitchell 1993]. One architect, however, claims that designing in 3D has reduced his drafting time by 30% [Smit]. 3D design probably requires more effort, not because 3D is inefficient, but because 3D design packs more information into the design drawings and requires less interpretation by those not privy to the design conception (contractors). To get over this obstacle designers should remember that their purpose in design documentation is to "try to construct a representation of the system" [Mitchell 1977], which is three dimensional in actuality. Universities must begin to stress this in their education of designers, and teach their students to operate 3D CAD systems. Designers should also review the many other benefits of having a 3D model (see [Smit] and [Reinschmidt et al. (1991)]) and realize that by making the investment they will be adding value to their work process and will be able to market new and improved services.

2. Database disparities

This issue involves creating a database that models the necessary objects in terms of performance for designers, and at the same time in terms of construction procedure for contractors. The Libraries and Project Database described in Chapter V have the capability to model objects in these terms, or views, via the attributes. Some of the views may be redundant or overlapping, but they are not incompatible pieces of information. The real issue is that it will take a monumental joint effort of clients, designers and contractors to develop and agree on these many attributes for the 360,000+ building components. This effort will be described in Section 5.

3. Information exchange level

The information exchange level proposed in Exhibit 4 in Chapter V was chosen so that the existing basic responsibilities of designers and contractors are maintained. To attempt to exchange information at the design analysis-estimate level or the design context-construction plan level depicted in Exhibit 4 would serve to disrupt the distribution of knowledge between designers and contractors. The proposed information exchange level allows the quantity takeoff task to be automated, which the author argues does not require knowledge. However, the selection of unit prices, the analysis of costs, and the development of a construction plan do require a contractor's knowledge and are proprietary. Just the same, a designer's analysis and reasoning about context represent knowledge and experience and are proprietary. It is important to understand that the proposal automates quantity surveying, and only attempts to assist the contractor in the estimating process.

The second issue involving the information exchange level is whether or not the shared object model can or should provide the recipient with the physical and sequential relationships between objects. A relationship is an attribute that relates that object to another object. These are needed to accurately understand necessary construction methodology for the objects or materials. Although physical relationships are inherent in the design and are available from the object model, they are not proposed to be represented explicitly as structured data, and contractors will be required to review and make sense of them. The relationships are unstructured in that an object's location is usually referenced from benchmarks like column lines and not from other objects. For example, contractors will need to review the concrete columns for location to determine if the concrete should or can be poured by crane or pump. There may be a conflicting object nearby keeping a crane from reaching and pouring the specific column. The Project Database can and should sort objects and materials by areas or sectors to make estimating and project management simpler. Sequential relationships between objects (actually between the tasks of constructing objects) are not inherent in present design practice and are proposed to remain determined by contractors.

There are complex relationships that are difficult to provide automatically with an object model. To attempt to include structured physical and sequential relationship information in the shared object model would disrupt the distribution of knowledge between designers and contractors. Thus the thesis proposes that contractors provide the relationship attributes that were referred to in Chapter V, Section C2 "Contractor's Project Database" as construction attributes. Contractors will have the choice of writing computer programs that automate the determination of these relationships, or browsing through the object model and determining them manually. This thesis proposal is generated under the assumption that the current procurement system of separating design and construction and hiring specialists in each be maintained.

4. Modeling objects versus attributes

Chapter V noted that all building materials that might ever be used separately from their normal building assemblies (e.g., a piece of reinforcing steel used as an exposed handrail) be modeled in the General Library individually. Chapter IV described the dilemma of deciding where to draw the line on a specific project between modeled objects and attributes of objects. Although projects may be modeled in as much detail as desired, it is suggested that effort be saved and the line be drawn like the current design practice of depicting common building assemblies. For example, an interior wall is a common building assembly that is currently depicted on drawings by two lines. In the object model proposed, the wall should be modeled as one object, with sheetrock, studs, fasteners and insulation listed as attributes. The quantity survey would total up each of these attributes. Paint, however, is typically listed separately in a finish schedule, and it is proposed that it be modeled separately.

Many objects, like the 7' X 3' door described in Chapter IV, will be constructed of many individual pieces of building materials. It will not be practical to list all of these as attributes in the quantity survey. Manufacturers of some products will be forced to perform an additional level of takeoff, like of the wooden stiles in doors, to accurately price their products. It is intended that the level of modeling be equal to the level at which contractors (or subcontractors), not fabricators, would purchase objects or materials. For example, contractors purchase solid core birch doors, not door stiles. Some elements of compromise must be instituted to make this proposal practical. The next section will suggest a forum for discussing these elements of compromise.

5. Standards organization to model the objects

Chapter IV described the need for one organization to develop standards and models for each type of building material and assembly. Unfortunately for the AEC industry there are numerous organizations and voices, public and private, that represent the industry concerning practices and standards. However, one organization, the National

Institute of Building Sciences (NIBS), was established by Congress in 1974 to address building industry issues; to encourage new technologies; and to collect, store, and disseminate information. This charter reads as if it were developed to execute this thesis proposal. Currently NIBS compiles and distributes quarterly an in-depth series of government and private guide specifications, regulations, building codes, graphic symbols, and material standards. This one source, called the Construction Criteria Base (CCB), includes almost all of the specifications and design criteria needed for construction in the U.S. It is distributed on four compact discs with read only memory (CD-ROM). CCB's use is already encouraged for designers by most of the large government agencies with construction budgets and is supported by design and building code societies. CCB receives written standards from over 120 building trade and code writing associations. See [*CCB Bulletin*] for a listing of the extensive participation in CCB. The point here is that the organizational infrastructure is already in place to work on establishing a standard format and to coordinate the effort of modeling objects and attributes for the General Library.

It is conceivable that with adequate funding NIBS, or any other similarly supported organization, could develop a standard format for modeling objects and attributes, and a plan for including all building materials. If NIBS is able to mobilize support and convince the 120 or more building trade associations that designers will tend to design around trades that are included in the proposed General Library, NIBS could motivate the associations to perform the modeling of their respective materials and assemblies themselves. The associations could list the objects, determine the attributes, and create the graphic commands. To get one organization to perform this for all building materials would be a monumental task and an undistributed cost. The support of the modeling standards by the building trade associations is needed anyway. The first key to this part of the proposal is that clients recognize the benefits of a shared CAD object model that will be summarized in the Conclusion and support the General Library's development. The second key is that architects, engineers and contractors grasp the benefits of the proposal and unite to help develop and promote standards, and to agree to support the use of the System.

6. Size and exchange of data

Chapter IV pointed out that to model all the potential applications of all building materials may require 180 megabytes of storage or more. It should be noted that one CD-ROM can store 650 megabytes of data. It is proposed that the General Library be created and updated regularly on a CD-ROM, similar to the CCB. A yearly subscription to CCB with quarterly updates costs only $970 [*CCB Bulletin*]. CD read-only drives are now common and very inexpensive: less than $500 for a PC. NIBS' cost to "burn" additional copies of the CCB onto CDs is less than $2 each [Kennett]. To create and access the Project Library and Project Database the designers will require read and write capabilities. However, since the objects used and repeated in the Project will be a fraction of the objects in the General Library, the amounts of data will be much smaller than required for the General Library. For these reasons magnetic tape drives and tapes, that are more common and less expensive than CD read and write drives and discs, appear practical for storing data and exchanging it with contractors. One exchanged tape (120 megabytes) might include all the CAD files and the Project Database for a large project. After contractors have installed the CAD and database software programs, they would need to open the project files via a tape drive unit. Designers and contractors alike will find that the receipt, storage and exchange of general and project data, although it may be extensively large, is quite practical through new data storage technologies.

7. Exchange standards

The problem of users not being able to communicate project data electronically amongst themselves whenever two users are not using the same CAD system is not limited to the AEC industry. Manufacturing industries including automotive, aerospace, consumer products and electronics manufacturing have realized the problems of not being able to concurrently and jointly prepare product designs across organizational boundaries (See [McDonald]). For this reason leaders in these industries have joined together behind a government initiative to develop and institute a file format and data schema exchange standard that builds on the IGES standard mentioned in Chapter IV. This initiative is called PDES, the Product Data Exchange using STEP, the Standard for the Exchange of Product model data. The standard is referred to as STEP. PDES intends for STEP to develop more than just graphics and geometry exchange capabilities; it will exchange intelligent objects, like concrete columns or beams. It does this by linking to distributed databases, like the Project Database proposed in this thesis. STEP, which is still in development, will have many advantages to users (see [Warthen] and [*Purchasing*]). One advantage is a proposed Generic Product Data Model (GPDM) of objects that designers in all fields commonly use. The proposed General Library could be considered the GPDM for the AEC industry. STEP is exactly what this thesis proposal needs for the AEC industry to adopt in order for the CAD System and Project Database files to be recognized universally by designers and contractors wishing to use the System. It is important to understand that STEP is not a CAD system; it is an exchange standard. However, the major CAD developers perceive it as a threat for users to switch to less expensive systems that can all read and write to the same files. Hence, most of the major CAD developers do not support PDES and their STEP effort.

The author argues that STEP is a viable exchange standard. The challenge of this proposal is to get the CAD developers to conform to it. Promoters of this thesis proposal may employ a strategy by proceeding with the creation of the General Library in the STEP format. (STEP is far enough along in development such that planning around its format may begin.) As noted in Chapter V, this would include objects, their attributes, and their graphic commands. A neutral organization, such as NIBS, developing the General Library would want to stay away from proprietary file formats anyway. The next step is to be able to create a Project Library from the STEP based General Library, and fortunately some commercial database developers are already supporting the PDES initiative. The third and important step will be to generate demand from the AEC industry for CAD systems that can read objects from the Libraries. Clients and designers will have to take the lead in demanding CAD systems that do this. It is conceivable that when the CAD developers begin to read these objects in STEP format that they will also write them in STEP format. This way the CAD and Project Database files may be exchanged with contractors universally who have STEP format CAD and database systems. Finally, it is important for the CAD developers to understand that STEP does not standardize the operation of CAD systems. CAD systems should differentiate themselves by their features and performance, and not by claiming to have the most desired file format. The agreement over the standard railroad gauge a hundred years ago did not end the differentiation in train locomotives because the three U.S. manufacturers continually compete with innovations [Edwards].

The scenario described in the previous paragraph appears to be putting the cart before the horse by attempting to get the General Library developed before CAD developers have agreed to work to it with an exchange standard. To avert this, AEC leaders will need to work with the PDES organization to monitor how other industries gather support for STEP. It is important that the CAD developers understand that they will still be able to differentiate themselves based on the performance of their systems. Also, contractors will begin purchasing CAD systems if they know that can use the one system for all of their projects on which they receive electronic files. It is crucial that CAD developers understand these benefits and get on board with PDES STEP.

Chapter VII. Promotion, Development, and Implementation of Proposed System

Even after solutions to the problems and issues have been suggested in Chapter VI, many aspects of the System proposed are not ready to be put into operation. To begin with, there must be a demand for integrating and sharing quantity surveys and other unconventional information with contractors. It must then be understood that the only way to be able to share this across the U.S. AEC industry is to develop a universally accepted language of objects and attributes. Afterwards, CAD and software developers will have little trouble developing the components of the proposed System. The AEC industry will undoubtedly experiment with many alternative ways of implementing the proposal. First, though, a number of recommendations may be made to get to the understanding of the need for a shared quantity survey and commence creation of the object language. This chapter will suggest steps that clients, designers, and contractors can take to promote, develop, and implement shared CAD object models.

A. Steps by Clients

The proposal for designers to share CAD object models with contractors relies almost entirely on the external motivation of clients as described in Chapter III. Contractors have no leverage in motivating designers to develop new CAD systems. Nor can they easily motivate them to share any more information than drawings or specifications. Designers are always inclined to improve their CAD tools, but not if it appears to just provide more information for the contractors' benefit. Clients, however, have a powerful motivating position in requiring the information tools that their designers use. An example if this is that in the past few years many clients have required their designers to use specific CAD systems that integrated with their facilities management CAD programs. In fact, the facilities management CAD programs were developed for clients on demand from clients. To date, besides a few ineffectual programs for small design-builders, no commercially available CAD application programs have been expressly built for contractors by CAD developers. The Naval Facilities Engineering Command (NAVFAC) CAD 2 acquisition program demonstrates the powerful ability of large clients to affect and improve the way designers handle project information, not just for their own projects, but for the entire industry. (For more information on CAD 2, see [Parfitt].) The following describes steps clients should be doing to promote the development and implementation of shared CAD object models and their quantity surveys.

In addition to rereading and comprehending the motivating factors described in this thesis in Chapter III, constructed facilities clients can continue to grasp the benefits of electronically integrating project information between designers and contractors. Clients may review the following articles about integration: [Carroll (Autumn 1991); Argie; Stowe; Jordani; Ross; Chamberlain; Yau et al.; Howard et al.; English; Reinschmidt et al. (1989)]. It is important that contractors be included in the integration. In financial terms, construction costs account for approximately 90% of project costs, (excluding the cost of land) and hence should command attention for improvement. The first concrete step clients can take is requiring designers to share CAD files with contractors, in addition to and just the same way they currently provide drawings and specifications. It will not take long for contractors to realize the benefits of CAD files, and soon thereafter the author predicts CAD systems to be standard equipment in most contractors' offices.

Standardizing the presentation of project information is one step for facilitating the electronic integration of project information. This is so designers and contractors can develop information systems that work from project to project. One simple step that clients can take to help institute standards is to promote the use of the CCB and ConDoc® programs described in Chapter VI. The most important, moreover difficult, task for clients of construction will be to organize and promote the development of the standard object language, or the General Library. The Department of Defense, as a large client of construction, initiated the standardized CCB program. The implementation and management of CCB were turned over to NIBS, a neutral and central organization. The same fashion of development needs to be organized for the General Library. A strategy was proposed in Chapter VI for distributing the development work among over 120 different building trade organizations. Clients should understand the benefits of a universal exchange standard (see [Warthen]), and develop the library under the STEP format, unless a better standard can be found. The developers will see that their efforts closely parallel the efforts of PDES to create the Generic Product Data Model (GPDM).

As the General Library develops, so will advancements in commercial CAD object models and databases. Clients will see the opportunity to suggest and then require the use and sharing of the object models. Specific materials and material assemblies may be experimented with incrementally as they are developed. Different arrangements for contractually defining the shared quantity survey may be experimented with, but not after a trial and feedback period for the designers and contractors. Implementation should be scheduled and gradual to ensure that designers and contractors are able to develop their information tools and operating procedures properly, and to maintain their support.

B. Steps by Designers

To support integrated construction designers should begin with one of the first issues of integration raised, i.e., understanding what information the next party (contractors) need to execute their work. Designers can become more involved with constructibility (including teaching it as universities) and understand how contractors estimate costs. The next step is to promote standardization and designers can use the CCB as a specification library. In addition to providing a standardized format for specifications, CCB's promotion will help to centralize the fragmented sources of information that plague the AEC industry. Designers should have little problem adapting to the ConDoc® format for integrating drawing and specification information, which will be a helpful step towards standardization.

By sharing CAD files with contractors now, designers will be opening up new means for contractors to be managing project information. This will open up new forms of communication between the two parties. There are many task contractors can be performing with CAD files now, and sharing them now will assist contractors in their preparation for 3D CAD object models in the future. Designers may also consider using some of the object models that are already developed, like the American Institute of Steel Construction's (AISC) link between graphics and an attribute database for all of the standard steel shapes [Trousdale]. This could be reviewed in-house, or shared with a contractor helping to check preliminary cost estimates.

Designers, specifically the institutes and societies that represent architects and engineers, should take steps to help organize the development of the General Library. They should also play an active role in selecting and modeling the attributes of objects to ensure that both design and construction attributes are included. Designers should recognize the trade associations that help to develop the General Library, and promote their services whenever possible. Finally, designers should pressure CAD developers to adopt STEP file format standards. Different file formats between CAD systems only serve to limit communication between designers, and often set up barriers to gaining contracts. Design firms attempting to perform work in the European Community in the near future may find that they will be required to provide CAD files in the STEP format. Firms without a STEP format CAD system or a translator to STEP may be excluded from work there. By promoting these standards, designers will be taking the necessary steps for the development of a universal CAD object model that may be shared for their own benefit and that of the entire AEC industry.

C. Steps by Contractors

Contractors may realize more leverage in promoting integrated construction than they thought they were capable of if they begin to request it and help develop it, rather than just operating in the status quo fashion. The author has found very little integration initiative to have been generated by contractors. There is no organized effort by the contracting associations to get designers to share CAD files. Ironically contractors may be considered to have the most to gain from shared CAD files. The first step that contractors can take to support this thesis proposal is to purchase and implement CAD systems (their prices may be surprisingly low) and begin to ask designers to share CAD files with them on their projects. Through CAD, contractors may find that they can communicate with and assist designers during the design stages, adding constructibility reviews as a preconstruction service. There are currently estimating programs on the market that link directly to CAD programs and allow takeoff to occur on the display screen. These programs still require substantial takeoff effort, whereas the inherent quantity surveys in the proposed Project Database require no takeoff effort, but they are an important first step towards integrating design and construction information. These estimating programs may also represent a significant leap in takeoff productivity. Contractors will also find that they are able to expedite and improve the coordination drawing process on CAD systems. Contractors will be able to use CAD to complete as-built drawings, which may be a requirement for many clients who want accurate CAD files to use with their facilities management programs.

Finally, contractors, specifically the organizations that represent them, can support the development of the General Library and assist in the modeling of objects and their attributes. Contractors who have implemented CAD will quickly understand the need for a uniform file format when they work with a designer that operates a CAD system with a different file format from their own. Contractors may purchase translator programs, but they will find that the translation is poor (see [Lang] and [Novitski Nov.-Dec. 1992]), and for this reason will be inclined to promote STEP or some other uniform file format.

As sharing CAD files becomes as common as sharing paper drawings and specifications, and as a standard General Library develops, contractors will find CAD and database systems on the market that can manage the information. However, it will require the offering of cooperative payoffs and persistence to get designers to share CAD object models, especially ones with quantity surveys.

Chapter VIII. Summary and Conclusions

This thesis set out to show that there are considerable inefficiencies in the way project information is transferred from designers to contractors under the most common construction procurement method in the U.S. (hiring designers and contractors separately). Information is transferred primarily via two dimensional drawings and specifications. Drawings consist of graphic representations that must be interpreted by contractors for meaning since the contractors do not know the designer's intent. Usually the graphic representations conform to a de facto industry standard, but often that is not possible. The balance of project information is transferred via written specifications that are supposed to have a direct correlation to the drawings, but often do not because of the complexities of each.

The development of a quantity survey by both designers and contractors for cost estimates was chosen for review and improvement because of particular inefficiencies in the process. Designers have imprecise and crude methods for estimating construction costs during design and comparing them to budgets, which often leads to the misnomer value engineering. Contractors, working in competitive bid situations, are forced to include in their quantity survey the minimum amount of materials whenever there is a question about the interpretation of the drawings or specifications. This is the first step towards the unfortunate change order wars that lead the industry to expensive litigation and adversarial relationships between designers and contractors. Finally, it is inefficient for all of the many bidding contractors to each make the same expensive effort to generate a quantity survey for the same project. Contractors are forced to pass on these problems and inefficiencies to constructed facility clients in the form of higher costs.

The thesis points out that Britain and other countries use a different system whereby one quantity surveying firm provides expert cost estimating knowledge to designers during design, and then prepares a single quantity survey for all bidding contractors, eliminating the need for interpretation and reducing costs to the industry. The thesis proposes to build on the British system's framework, but to replace the quantity surveyor with a 3D object model CAD system that creates and then shares quantity surveys with contractors. Many design-build firms are currently doing this within their own organizations. This thesis proposes to implement a computer integrated approach in the context of traditional project procurement, i.e., separate designer and contractor. This will maintain the benefits of the existing distribution of knowledge and responsibility domains between designers and contractors. Designers can continue to specialize in "what" to build and contractors in "how" to build it.

A. Benefits of Proposal

The proposal is considered to be a composite information system (CIS) in Osborn's terms [Osborn et al.] whereby two independent parties, in this case designers and contractors, develop one system from which both can benefit. This CIS, due to the fragmentation and lack of dominant leaders in the AEC industry, relies heavily on external motivation from large clients of construction, like the U.S. government, to ever be implemented. The first type of benefits for clients are intangible. One is the reduction in friction between clients, designers, and contractors due to a common quantity survey that will eliminate misunderstandings over interpretation of drawings and hence reduce litigation, saving time and money. Another is that clients will be able to get more value in their projects due to the designer having more knowledge and control over cost during design.

The tangible motivating benefit for clients is that the cost of construction will be reduced. Contractors will save the cost of takeoff (minus the cost to purchase the necessary hardware and software) and will have their risk reduced by bidding from a shared quantity survey. The thesis argues that market forces will return the savings to clients via lower bids. Designers will be entitled to additional fees for their cost to purchase and operate the proposed System. A calculation of the net savings in the majority "plans and specs" procurement, based on a number of assumptions included in the thesis, is as follows:

costs:	from designers	-.10%	of const. value for added equipment, work and responsibility
benefits:	from contractors	+.32%	of const. value for net estimating cost savings after equipment costs
		+.50%	of const. value for risk reduction
net benefit:		.72%	of const. value
for annual non-residential, plans and specs construction in the U.S.		.72%	X $220 bil. const. value= $1.58 billion

The proposed CIS provides internal motivation, or benefits to designers and contractors. Designers' benefits include being able to track and control project costs better during design, and hence design more value into projects. The System will also help them create higher quality contract documents by integrating the drawings, specifications, and quantity survey. Designers will also benefit from higher fees. Contractors will be able to bid on more projects with the same size estimating crew, and will be able to focus more on unit prices, complete scopes, and construction methodologies, effectively increasing their differentiation. Most contractors will enjoy the swap in fees for a reduction in risk.

B. System Proposed

The System proposed relies on the creation of a complete listing of every construction material's uses, attributes, and graphic commands in a General Library. This General Library will serve as the common language from which designers will create design documents. Contract documents will consist of CAD object files and the linked Project Database, containing the attributes whose sum is a quantity survey, and will be exchanged with bidding contractors. (Designers may also continue to exchange paper drawings and specifications.) Contractors and designers will each have estimating systems on which they will match the quantity survey with their own unit price databases. Although beyond the scope of this thesis, the System will also encourage the development of other design and construction applications such as engineering analysis and project scheduling.

C. Issues Concerning Development and Implementation

A series of organizational and technological issues are presented and later responded to. Three issues stand out as needing the most attention. First, the cost to benefit ratios for clients, designers, and contractors need to be more accurately defined. Before proceeding with the proposal contractors will want to calculate more accurately their potential savings in takeoff costs. They will need software and hardware costs defined, and will want to ensure that operation and maintenance costs do not exceed present estimating costs. Designers will want to verify that they will be able to command the extra fees proposed. They will want to ensure that the General Library, software, hardware and operation costs do not exceed the extra fees. Before clients sponsor the development of the General Library they need to verify the net savings and appreciate the intangible benefits mentioned previously.

The second major issue is that designers will need to accept the additional responsibility (with a higher fee benefit) for providing adequate details in the CAD and database files. This is necessary to generate a detailed and complete quantity survey and will serve to tighten the project communication link between designers and installers/ fabricators. General contractors will eventually need to maintain a core competency in construction as the computer begins to handle more and more coordination.

The third and most difficult issue is the organization of the effort to develop the General Library. The General Library must represent every common use of every common building material in an exchange standard that is accepted by the many designers, contractors, and building trade organizations in the fragmented AEC industry. The thesis suggests that large government clients (many already support integrated construction) sponsor an organization such as the National Institute of Building Sciences (NIBS) to create the General Library. NIBS already has a system for networking 120 plus building trade and code writing associations for standards. The thesis suggests that the General Library be established in the non-proprietary and international exchange standard, STEP. The thesis argues that market demand will attract CAD developers to read and write the object files in STEP format.

The thesis suggests that individual design and construction firms can promote the System now by supporting standardization and integration. Designers can support the standardization of specifications through the CCB program and drawings through the ConDoc® program. Designers can electronically integrate with contractors by sharing CAD files. Contractors should begin implementing CAD systems for many uses, and ask designers to share project CAD files with them. Contractors could offer constructibility and cost estimating preconstruction services as a means to integrate early in the construction process. Both designers and contractors can promote STEP by implementing software that is compatible with the emerging STEP standards.

D. Long Term Benefits

This thesis demonstrates that there are benefits to integrating and sharing information between designers and contractors beyond the historical method of exchanging paper drawings and specifications. The development of the quantity survey was addressed by this thesis because it is a logical first step towards integrated construction. Design-build firms are currently using their proprietary object model CAD systems to integrate engineering analysis, scheduling, construction simulation, procurement, accounting, and computer aided manufacturing (CAM). However, design-build is not an acceptable procurement method for most types of construction in the U.S. The power and capability of an object model are immense, and distributed designers and contractors have the ability to develop jointly these integrated capabilities, helping themselves and clients by constructing better quality facilities for less money and in less time. The shared Project Database will serve as the platform for communication and integration. Integrated construction is necessary for keeping the U.S. AEC industry, and all the U.S. industries that rely on it for constructed facilities, competitive with foreign industry.

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