ABSTRACT

Title of Document: BUILDING INFORMATION MODELING INTEGRATED WITH ELECTRONIC COMMERCE MATERIAL PROCUREMENT AND SUPPLIER PERFORMANCE MANAGEMENT SYSTEM

Yali Ren, M.S., 2011

Directed By: Professor Miroslaw J. Skibniewski, Department of Civil & Environmental Engineering

Traditional construction material procurement is being replaced by electronic commerce construction material procurement now. Building Information Modeling (BIM) has shown benefit and practical value in construction material quantity takeoff and cost estimate. However, very few efforts have been directed to the application and integration of BIM in e-commerce material procurement.

The author compares the present commercial BIM and non-BIM based quantity takeoff and cost estimate software, presents one solution to link the BIM with RSMeans Unit Price cost data to generate more accurate cost estimate reports, identifies the possibility and potential benefit of integrating BIM and e-commerce software solutions in material cost estimate and procurement process, designs one weight coefficient based model to evaluate the performance of material suppliers,

proposes a framework to integrate BIM with e-commerce in material procurement and supplier performance evaluation process, and develops a preliminary display version of BIM integrated with e-commerce software system.

BUILDING INFORMATION MODELING INTEGRATED WITH ELECTRONIC COMMERCE MATERIAL PROCUREMENT AND SUPPLIER PERFORMANCE MANAGEMENT SYSTEM

By

Yali Ren

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Advisory Committee:
Professor Qingbin Cui, Chair
Professor Miroslaw J. Skibniewski
Professor Carl H. Bovill

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1 Introduction

1.1 Background

The construction materials can typically account for around 40% to 45% of the total cost in construction industry (Agapiou and Flanagan, 1998). Presently, lots of construction firms adopt web-based electronic commerce (e-commerce) system to communicate directly with material manufacturers, suppliers, agents and application service providers to purchase construction materials. E-commerce creates a solution for material procurement using non-traditional method and a win-win situation for most construction material transaction participants (Kong and Li, 2004). However, the scope of the construction e-procurement system has limitation to streamline the workflow during the quantity takeoff, estimating and bidding and procurement stages of the preconstruction interactions among suppliers, contractors and designers (Castro-Lacouture and Medaglia, 2007). Serious interoperability problems still hinder the further taking up of electronic business tools (Mell and Grance, 2010).

Building Information Modeling (BIM) is the process of generating and managing building data during its life cycle. Typically, this process uses three-dimensional, real-time, dynamic building modeling software and it covers geometry, spatial relationships, geographic information, quantities and various other properties to facilitate building design process (Castro-Lacouture and Medaglia, 2007). BIM is changing the way Architecture, Engineering, and Construction (AEC) sectors are working and providing new processes for design solutions and construction collaboration (Grilo and Jardim-Goncalves, 2010). Compared with traditional methods, BIM provides one solution that makes material quantity takeoff and cost estimate easier, faster, cheaper and more accurate. By using a BIM drawing instead of CAD drawings, the material takeoffs, counts, and measurements can be generated, revised and updated directly from the underlying models, which potentially saves time, cost and labor efforts, and facilitates the ease for collaboration and cooperation between various participants during material procurement process. BIM integrated with e-commerce software application provides potential benefit of streamlining the workflow of material quantity takeoff, estimating, bidding and procurement stages of the preconstruction interactions among various construction participants (Holness, 2008). BIM also facilitates a variety of related material procurement activities including material specifications description, design to digital fabrication and quality inspection process. However, very few efforts have been directed to the application of BIM in construction material e-procurement (Grilo and Jardim-Goncalves, 2011), and no commercial BIM integrated with e-commerce software system for material quantity takeoff, cost estimate or procurement has been designed or developed by construction software vendors.

Construction material supplier performance evaluation and information management is one important part of material procurement process, and is the reference for selecting appropriate material suppliers in e-awarding workflow. An improved and effective material supplier performance evaluation method is vital for the procurement success and project profits of construction contractors and sub-contractors. BIM integrated with e-commerce material system solutions provide one innovative approach and improved way for material procurement process, and supplier performance evaluation model based on BIM integrated with e-commerce material software system solutions will be more accurate and precise. Therefore, it will be of useful value to incorporate a practical supplier performance evaluation and information management function in the BIM integrated with e-commerce construction material procurement software system.

1.2 Research Objectives

The main objective of this research is to propose a BIM integrated with e-commerce material procurement framework, present BIM based quantity takeoff and cost estimate solutions, and design improved supplier performance evaluation model, and develop an elementary version of BIM integrated with e-commerce software system for construction material quantity takeoff, cost estimate, bidding, tendering, awarding, material procurement and supplier performance evaluation process to reduce time and labor cost, streamline the workflow, improve accuracy and efficiency, collaboration and cooperation in this process.

To achieve the objective of this study, the following research questions are addressed as primary research questions:

- What are the application, benefit, limitations and barriers of e-commerce and BIM in construction material quantity takeoff, cost estimate and material procurement process?

- Is it possible to integrate BIM with e-commerce software solutions in construction material quantity, cost estimate and procurement process? If so, what might be the benefit?

- What is the suitable BIM integrated with e-commerce framework that could be applicable for material quantity takeoff, cost estimate, material procurement and supplier performance evaluation and information management process?

- What might be an applicable BIM integrated with e-commerce software tools based supplier performance evaluation and information management model?

The primary research tasks comprise the following aspects:

- Identify the application, benefit, limitations and barriers of e-commerce and BIM in construction material quantity takeoff, cost estimate and procurement process.

- Compare the present commercial BIM based and non BIM based quantity takeoff and cost estimate software, choose an applicable BIM development platform and a suitable material cost criterion source, and design and develop a BIM based material quantity takeoff and cost estimate software module to provide more accurate material cost information as the basic cost standard to evaluate the quotes from the future potential suppliers in the bidding, tendering and awarding process.

- Design and develop an e-commerce based material procurement management system to implement tendering, bidding, awarding management, transaction history management, supplier evaluation and information management, and project document and information management functions, and material specifications should be described using BIM in project documents.

- Provide an effective supplier performance evaluation model, design and develop user-friendly performance evaluation and supplier information management interface to provide valuable reference for construction contractors to select and manage the potential future material suppliers.

- Propose the BIM integrated with e-commerce framework in material procurement process and develop the elementary display version of software system for the integration of BIM and e-commerce in material quantity takeoff, cost estimate, material procurement and supplier performance evaluation and information management process.

2 Literature Review

2.1 Traditional Material Procurement Process

2.1.1 Traditional Material Procurement Workflow

The traditional material procurement process includes generation, copying, and transfer of many paper documents during various procedures like requisition of materials, quotation, purchase order, etc.; and it involves many parties like staffs in buying department, accounting department, site office and supplier's office (Kong and Li, 2004). Figure 1 shows the traditional construction material procurement workflow from the general contractor perspective.

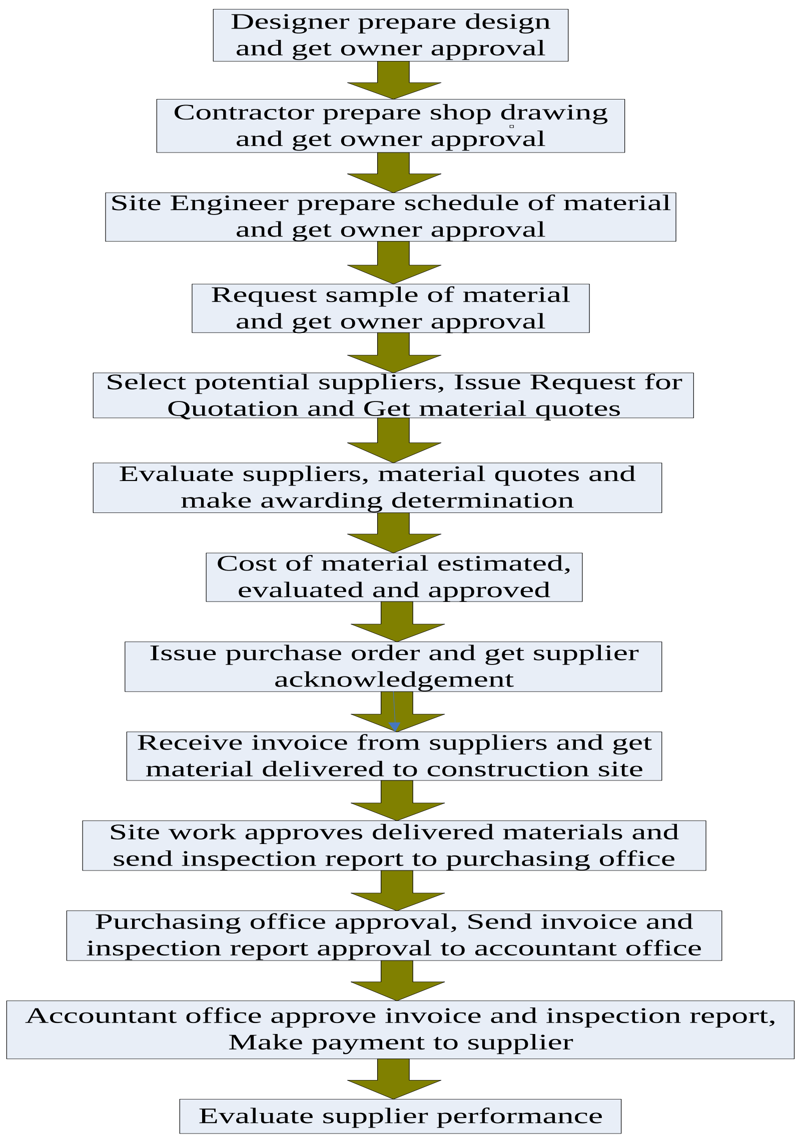


Figure 1 Traditional Material Procurement Workflow

2.1.2 Drawbacks of Traditional Material Procurement Process

The traditional material procurement process has many drawbacks: low accuracy, time consumption, labor consumption, loss of data and high uncertainty, which are shown in the following aspects (HadikusumoT and Petchpong, 2005):

- Long time work of material quantity takeoff and cost estimate
- Tedious modification work when design or shop drawing changes
- Improper material schedule for site requirement
- Limited, not updated, improper material and supplier information
- Uncompetitive material quality and price for information restriction
- Unclear or wrong material specification, date, time, defect materials delivered
- Lost or incorrect material, payment or schedule information
- Difficulty in getting sample of materials for approval
- Failure or miscommunication to get specification changed by owner
- Unclear or missed paper documents
- Various communication problems inside or outside design-build construction firm
- Time consuming, higher cost, more dispute or claim for the procurement process

Hence, an effective material management is important for project profit and success.

2.2 Electronic Commerce in Material Procurement

2.2.1 Electronic Commerce in AEC

Electronic commerce (e-commerce) is the sharing of business information, maintaining business relationships, and conducting business transactions by means of telecommunications networks. E-commerce includes the sell-buy relationships and transactions between companies, as well as the corporate processes that support the commerce within individual firms (Zwass, 1996). E-commerce can be broadly divided into four main categories (Anumba and Ruikar, 2002): Business-to-Business (B2B), Business-to-Consumer (B2C), Business-to-Administration (B2A) and Consumer-to-Administration (C2A). Business-to-business (B2B) e-commerce has been expected to grow rapidly because of the significant diffusion of the Internet Information since the early 2000s (Grilo and Jardim-Goncalves, 2011).

The oldest, simplest, and most widespread way of the collaborative procurement in AEC is the exchange of files through e-mail. Nowadays, electronic informational, transactional, and collaborative are likely to occur on building or engineering projects in construction firms. However, the degree of sophistication may vary from the simple use of e-mail or having a webpage with basic information to intense electronic marketplace transaction or use of a complex collaborative tool with workflow (Grilo and Jardim-Goncalves, 2010). The deployment of private extranets allows disparate parties in construction projects to share information by uploading and downloading files on a central server. More recently, several commercial web-based collaborative tools have appeared in the market, with very complex functions such as on-line CAD red-lining and markup, forums and logs registration. Commercial tools like Buzzsaw or ProjectNet of Citadon are now widely used, and more recently many other web 2.0 like tools have emerged with similar functionality in construction industry (IAI/IFC, 2010).

2.2.2 E-Commerce in Construction Material Procurement

2.2.2.1 Emergence of E-Commerce Material Procurement

Procurement plays a significant role in the AEC industry supply chain. Procurement activities are quite intensive and important in the AEC sectors (Grilo and Jardim-Goncalves, 2011). The generic concept of "procurement" supports a delivery relationship between buyers and sellers. Procurement can be divided into two phases: contracting and settlement. The contracting phase consists of sourcing and availability to promises, and the settlement phase consists of transaction and delivery (Grilo and Jardim-Goncalves, 2011).

The architecture, engineering, and construction sectors have embraced e-commerce and e-business and in the use of electronic collaborative and e-commerce platforms in material procurement (Grilo and Jardim-Goncalves, 2010). E-commerce procurement refers to the electronic exchange of commercial data related to the transaction life cycle from the request for quotation, order, until invoice. Electronic procurement (e-procurement) emerged from the early adoption of the Internet by business and was linked to the surge of inter-organizational systems, communities, electronic platforms, meeting places, virtual locations and infrastructures (Grilo and Jardim-Goncalves, 2011). Vitkauskaite and Gatautis identifies 12 internal current processes of small to medium construction enterprises (SMEs) and the four most important ones selected out of them are e-Tendering, e-Site, e-Procurement and e-Quality (Vitkauskaite and Gatautis, 2008). Before the availability of the Internet as a communication network, companies used X.25-based technology for virtual areas networks (VANs) to exchange Electronic Data Interchange (EDI) message, but the use is mainly restricted between builders' merchants and their suppliers. The emergence of the electronic markets during the early 2000s has dramatically changed the use of electronic transactions, with contractors, suppliers, builder merchants, consultants and clients using these e-commerce platforms to request quotations, orders, and invoice (Grilo and Jardim-Goncalves, 2011).

2.2.2.2 E-Commerce Procurement Platform

With E-Commerce material procurement system, material sellers can upload their product information and find out summary information about their customers and transactions. Material information may include the attributes of each type of material, which include unit, width, height, depth, unit weight, material, unit price, currency, brand, standard, country of manufacturing, image, drawing, and additional material description files (Kong and Li, 2004). The buyers can provide their requirements such as brand, model, quality, price and etc. to search and browse different types of products and make transactions with low transaction costs at any time and any place which is convenient to them (Li and Cao, 2002). E-procurement construction trading markets are not limited by the time and space limitations of store spaces and can carry a much larger variety of products and different styles and sizes. E-Commerce procurement platform provides a central working platform for all construction material procurement participants and other related suppliers, which is shown in Figure 2:

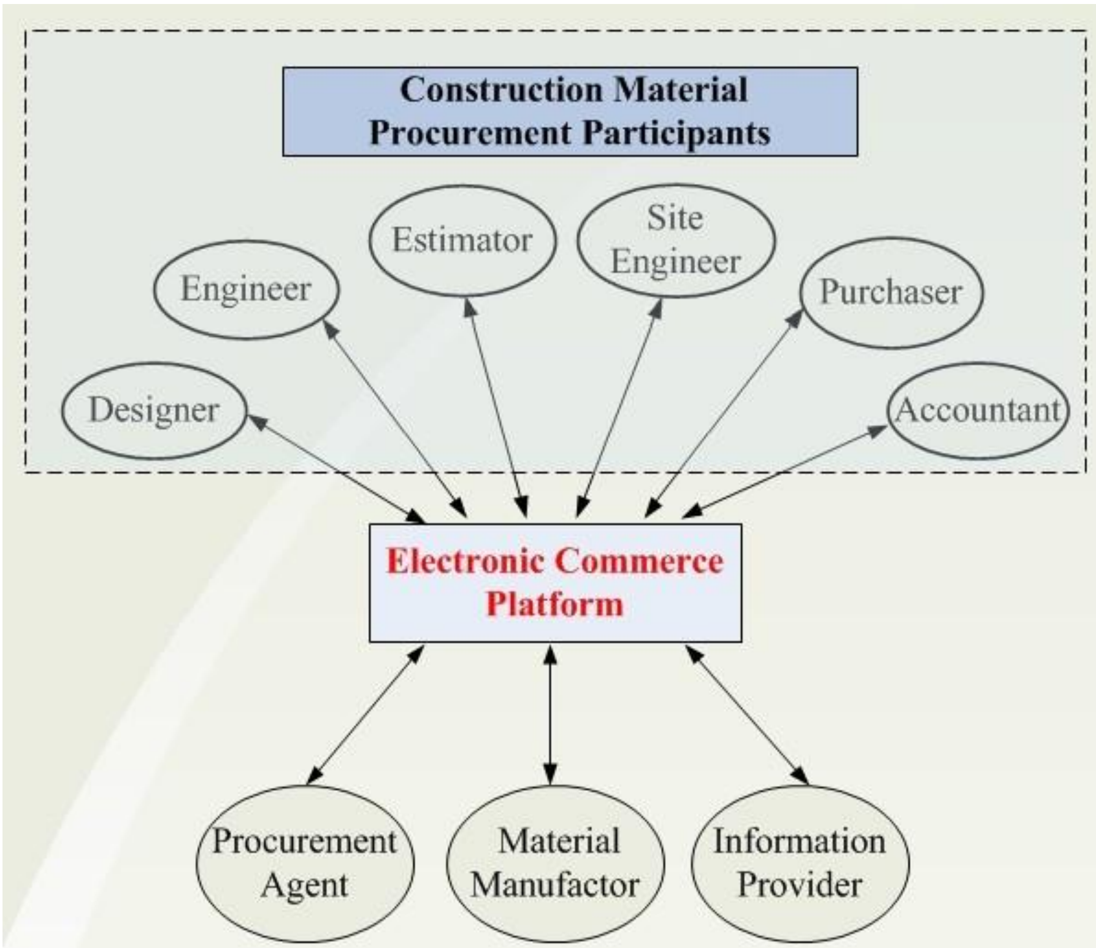


Figure 2 E-Commerce Platform for Construction Material Procurement Participants

2.2.2.3 Reference E-Procurement Process

Grilo and Jardim-Goncalves presented the Reference e-Procurement Process as in Figure 3:

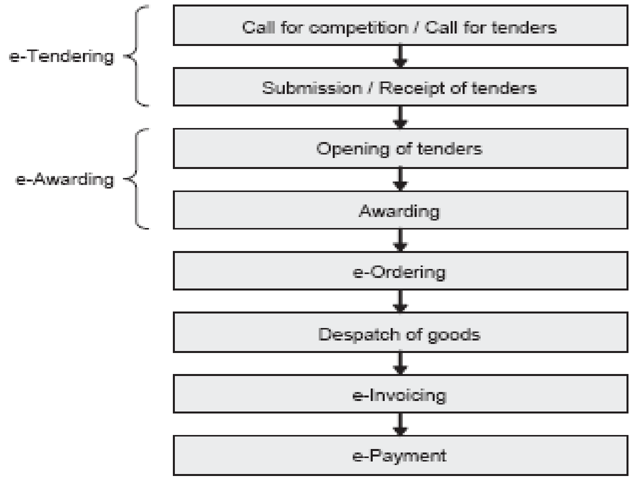


Figure 3 Reference e-Procurement Process (Grilo and Jardim-Goncalves, 2011)

2.2.2.4 E-Procurement Websites

Webpage describing companies' services and products are the simplest and most common usage of an e-procurement by AEC players (Grilo and Jardim-Goncalves, 2011). Two examples of construction tendering, biding and procurement related websites are shown in Table 1:

General Classification	Function/Description	Web URL
Project management and collaboration	Share project documents, and on-line document management. Main services: upload or download documents, on-line modification, storage document, modification notes, pursue document status	www.activeproject.com www.buzzsaw.com www.buildonline.com www.citadon.com www.loadsping.com
Project bidding and procurement	Provide construction products and services. Main services: electronic bidding, on-line product/service classification, price data exchange, bidding management, on-line purchasing	http://www.isqft.com/new/ www.ebidsystems.com www.eu-supply.com www.purchasepro.com http://postclick.datafax.net/ http://www.constructionwire.com/ http://www.bidclerk.com/ http://www.combinenet.com/

Table 1 Construction Tendering, Biding and Procurement Related Website

2.2.3 Benefit of E-Procurement

Literature review has revealed that e-procurement is the enabling technology that allows businesses to increase the accuracy and efficiency of business transaction processing (Trepper, 2000) and can decrease the costs of B2B transactions (Malone and Laubacher, 1998; Lucking-Reiley and Spuiber, 2000). E-Commerce procurement utilizes electronic media and information technology to streamline many working process, cut off the multiple layers between construction suppliers and buyers, enhance the operations of a project, and promote integration and operation through the shared information network system for diverse participants in the construction supply chain (Jones and Saad, 2003). E-Commerce facilitates the transaction process by providing more transparent material and supplier information, clear electronic document and material specification, less lost or incorrect information, reduced communication barriers, more updated supplier information and improved competition between suppliers (Li and Cao, 2002), reduced production costs, value creation such as paperless documentation, secured and searchable storage, real-time operation and monitoring (Zhou and Muller, 2003), improvement in business practices and processes, tighter integration of business, and more lean, agile and responsive to business demand, increase the employee's productivity and customer satisfaction and business transactions across multiple geographical boundaries in real time and enables the buyers to efficiently purchase cheaper, accurate and high-quality materials (Kalakota and Macia, 2001)

2.2.4 Limitations and Technical Challenges of E-Procurement

2.2.4.1 Limitations

E-procurement in AEC has certain limitations and it is rarely explored to its fullest in construction despite the availability of this technology. Grilo and Jardim-Goncalves identified that the AEC sectors are still lagging behind other sectors like retailing and automotive in the adoption of e-procurement (Grilo and Jardim-Goncalves, 2011). There are serious interoperability problems hindering the further taking up of electronic business tools (Mell and Grance, 2010). A typical reason lies in the lack of integration of the companies' internal ERP systems with the marketplaces. Thus, most of the companies type the transactional information into a web browser and receive data in a file that prints before re-introducing data manually into their ERP system (Mell and Grance, 2010).

E-procurement process first requires construction contractors to spend a long time in material quantity take off, site schedule requirement, cost estimation, supplier price and information search, and contact with suppliers and inquiry about specific information. When any change or alteration is made to any one drawing or document, architects or engineers have to make related changes or alterations in each related drawing, and contractors, estimators have to modify relevant material specification, quantity takeoff and estimate data, and site engineers have to arrange new site schedule of material requirement. This process requires huge collaboration and cooperative work between designers, engineers, contractors, estimators, site staffs and purchasers, which is a time-consuming and lengthy task, and may lead to errors, mistakes, or modifications being missed out and overlooked, even there are minor unfavorable issues happening in this process (Ruikar and Anumba, 2003). E-procurement has limitations in dealing with the above practical problems. The scope of the construction e-procurement system has limitation to streamline the workflow during the take-off, estimating and bidding stages of the preconstruction interactions among suppliers, contractors and designers (Castro-Lacouture and Medaglia, 2007).

2.2.4.2 Technical Challenges

Literature review shows that e-procurement might not be suitable for detailed specification of goods or services where close relationships between buyers and suppliers are essential (Subramaniam, 2004; and Luvsanbyamba, 2011). This might be the case in the AEC sectors, where many of the procured goods and services may have a large number of complex levels of specifications parameters (Grilo and Jardim-Goncalves, 2011). Entering the specifications into web-based forms of several e-commerce sites to find the best product is a time consuming task for a contractor. A contractor has to acquire and maintain a list of several web addresses, interpret and understand the semantics and navigation methods used in different sites, be aware of new sites coming into the market, and do a manual evaluation of all the information acquired from different websites (Kong and Li, 2004). The aggregation of information through e-marketplaces may overcome some of these difficulties but does not eliminate them (Pahwa and Burnap, 2006). Different e-marketplaces have their own material searching and display patterns and use different attributes for storing construction material data (Kong and Li, 2004). When two suppliers sell the same or similar products store descriptions differently using different attributes, it becomes difficult for a contractor to identify the similarities and differences. Construction material information systems are isolated and have no interaction between them (Kong and Li, 2004). Although request for quotations/proposals may reduce part of the problem if the information product is highly structured, in general it is difficult for a contractor to find all the information using one system and even more difficult to do a comparison of the products supplied by different suppliers based on criteria such as product specification, cost, availability, and delivery time (Empirica GmbH, 2007). Grilo and Jardim-Goncalves points out that the AEC sector is characterized by the procurement of high levels of unstructured goods and services and it makes the use of electronic systems for procurement activities more difficult, so e-procurement solutions must be able to develop ways to successfully cope with the challenges of procuring unstructured goods and services (Grilo and Jardim-Goncalves, 2011).

E-procurement presents several other technical challenges that create interoperability concerns regarding public procurement at the European and global scales. The two most important initiatives/standards developed by international standardization bodies in the area of e-Catalogues are the UBL 2.0 and c-Catalogue, developed by OASIS and CEN/ISSS, respectively (CEN/ISSS Workshop, 2005). Both standards focus primarily on post-award phases of procurement (e-ordering and e-invoicing), while their specifications can also be applied for pre-awarding, possibly following some extensions/customizations (Grilo and Jardim-Goncalves, 2011). Even though electronic signatures are relatively widespread today, in practice certification authorities do not recognize each other in every case, thus creating identification hurdles, so electronic signatures interoperability is also a significant issue, despite the existence of technical standards available, such as X.509v3 for electronic certificates. Presently, current CEN/ISSS standards of e-tendering, e-awarding, and e-ordering, along with e-signatures are sought to be followed in a less critical way (Grilo and Jardim-Goncalves, 2011). E-ordering and e-invoicing are less challenging issues as the ongoing standardization work in CEN/ISSS WS/BII (CEN/ISSS Workshop on Electronic Procurement, 2005) is becoming mature and these business documents are now standardized and XML-based (Grilo and Jardim-Goncalves, 2011).

2.3 Building Information Modeling in Material Procurement

2.3.1 Definition of Building Information Modeling

Building Information Modeling (BIM) has become an active research area to solve the problems related to building information integration and interoperability (Isikdag and Underwood, 2010). Several definitions of BIM can be found in the technical literatures. Penttila defined BIM as a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Penttila, 2006). The NBIMS divides the BIM categories in three axes which are Product, Collaborative Process, and Facility. The Product is an intelligent digital representation of the building. The Collaborative Process covers business drivers, automated process capabilities and open information standards used for information sustainability and fidelity. The Facility concerns the well-understood information exchanges, workflows, and procedures in which teams use as repeatable verifiable and sustainable information-based environment throughout the building's lifecycle (NBIMS, 2007).

The core attributes of BIM that distinguishes it from the design technologies is that it is not three dimensional geometric modeling, but structured information that is organized, defined and exchanged (Smith and Tardif, 2009). The way to understand BIM should be focused on the business process used to create modeling instead of model (Smith and Tardif, 2009). BIM structured information opens the door to easier and more effective building information transfer at every critical juncture of building stewardship transfer (Smith and Tardif, 2009). BIM opens the door to ample, even remarkable business opportunities for those architects with insight to perceive and exploit them (Smith and Tardif, 2009), and to maintain an accurate and more complex documentary record of building information throughout the building design and construction process. BIM allows architecture profession to assert a leadership throughout lifecycle of buildings. BIM includes three interrelated fields which are policy, process, and technology fields as shown in Figure 4:

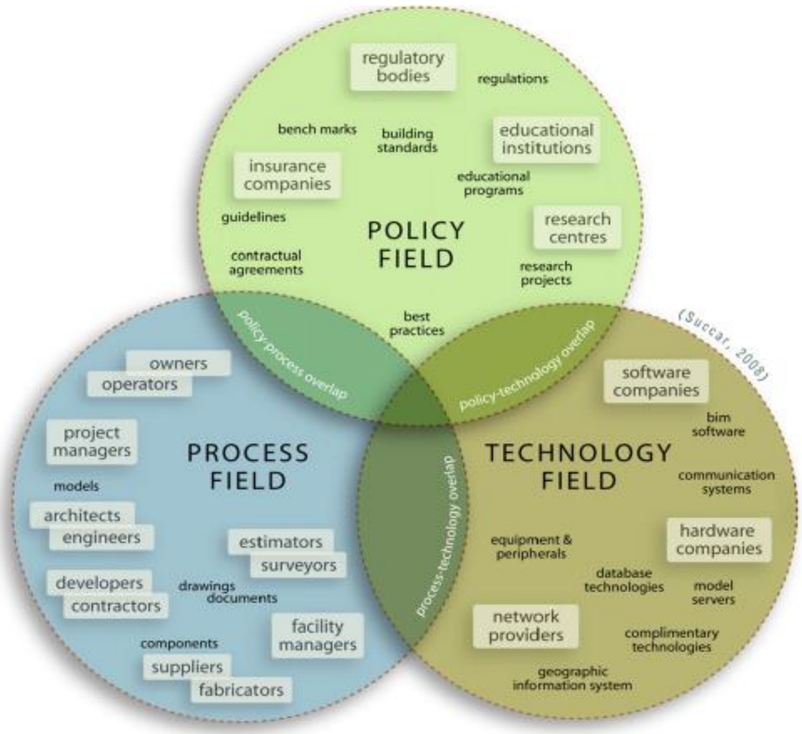


Figure 4 Three Interrelated Fields of BIM (Succar, 2009)

2.3.2 BIM Capability Stage and Maturity Model

2.3.2.1 BIM Capability Stage

BIM Capability is the basic ability to perform a task or deliver a BIM service/product. BIM Capability Stages (or BIM Stages) define the minimum BIM requirements - the major milestones that need to be reached by teams or organizations as they implement BIM technologies and concepts. Three BIM Stages separate 'pre-BIM', a fixed starting point representing industry status before BIM implementation from 'post-BIM', a variable ending point representing the ever evolving goal of employing virtually integrated Design, Construction and Operation (viDCO) tools and concepts (Succar, 2010):

BIM Stage 1: object-based modeling
BIM Stage 2: model-based collaboration
BIM Stage 3: network-based integration

Three BIM stages are shown in Figure 5：

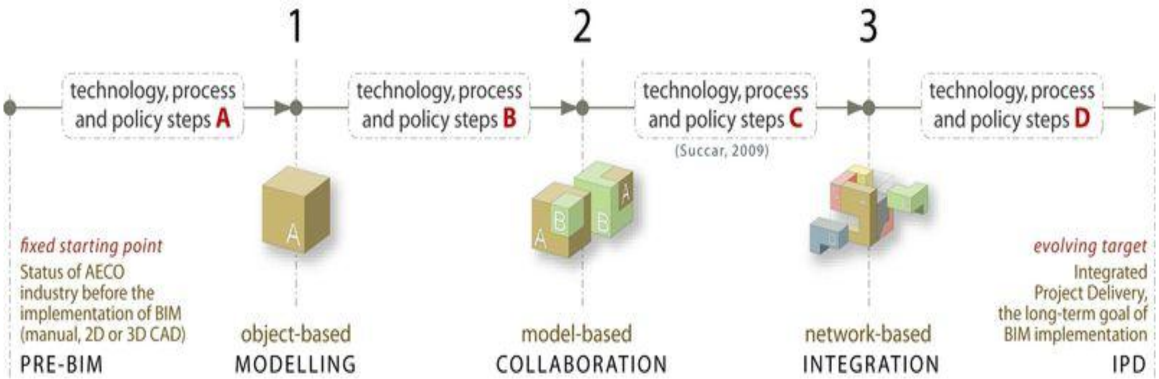


Figure 5 Three Different Capability Stages of BIM (Succar, 2010)

An organization is considered to have reached BIM Capability Stage 1 by the relative easiness of deploying object-based software tool similar to ArchiCAD, Revit, Tekla or Constructor. BIM Capability Stage 2 is reached when an organization undertakes model-based multi-disciplinary collaboration. Finally, BIM Capability Stage 3 is reached when an organization undertakes network-based (like model servers or BIMSaaS) interdisciplinary model integration (Succar, 2010).

2.3.2.2 BIM Capability Maturity Model

The Capability Maturity Model of National Building Information Modeling Standard is a good first step toward establishing BIM implementation benchmarks (Smith and Tardif, 2009). The term 'BIM Maturity' refers to the quality, repeatability and degrees of excellence of BIM services. In other words, BIM Maturity is the more advanced ability to excel in performing a task or delivering a BIM service/ product. Maturity Models (CMM) reflects the specifics of BIM technologies, processes and policies.

BIM Maturity Index (BIMMI) has been developed by investigating and then integrating several maturity models from different industries. BIMMI is similar to many Capability Maturity Models (CMM), but reflects the specifics of BIM technologies, processes and policies. BIMMI has five distinct Maturity Levels: (a) Initial/ Ad-hoc, (b) Defined, (c) Managed, (d) Integrated, (e) Optimized (Succar, 2010), which is shown in Figure 6:

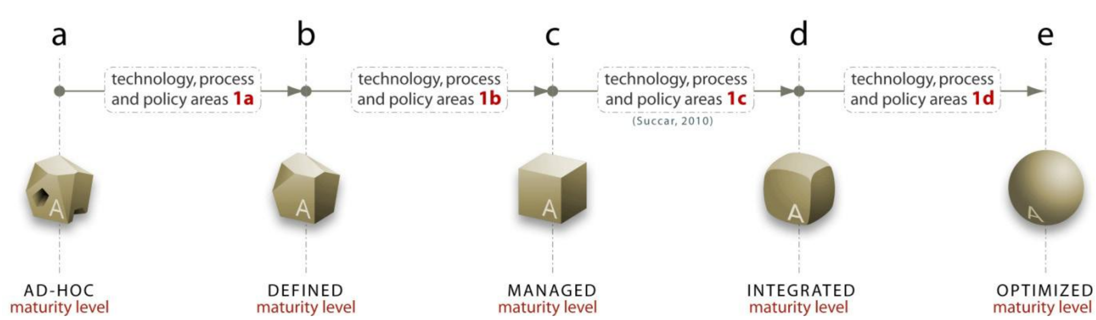


Figure 6 Five BIM Maturity Index Levels (Succar, 2010)

2.3.3 BIM as a Collaborative Working Environment

Fragmentation is a key feature of the construction industry structure and client base. The traditional nature of the industry involves bringing together multi-disciplines/practitioners in a one-of a-kind project which requires a tremendous amount of collaboration and coordination (Isikdag and Underwood, 2010). BIM is changing the way companies in the AEC sector are working, providing new processes for collaboration (Grilo and Jardim-Goncalves, R2010). Building Information Models (BIMs) are promising to be the facilitators of integration, interoperability and collaboration for the future construction industry (Isikdag and Underwood, 2010).

BIM refers to process comprehensively managing information being generated throughout the processes and not just simple information model. The continuity of information and workflow that BIM fosters provides a powerful incentive for early and intensive collaboration (Smith and Tardif, 2009). BIM allows applications to exchange and share data using various procedures including STEP, IFC, XML which are being developed for the interoperability of data in ISO International Organization for Standardization (ISO) and International Alliance for Interoperability (IAI) to solve the problems of data compatibility and being interpreted differently by different software (Ham and Min, 2008).

Interactions are important in virtual building simulations, and various types of links may be established during the development of composed BIM models. Indeed, interactions refer to the interconnection of different sources of information. This information may be part of the 3D model, or it could be contained in another format separate from the model file itself, such as in a schedule, a spreadsheet, a database, or as a text document. Whenever the interaction involves the components of the 3D model, a common link in BIM needs to exist, i.e. the interoperability of various models that may have been created by different software tools is required (Innova, 2008).

There are great efforts being made to develop standards to define interoperability between models. This means that, for a model to be compatible with models created by other software tools, it is necessary for all of them to be translatable into a file format, so that all of the object's information can be transferred correctly. In most cases it is a challenge for such a translation to retain all the information that the model contained in its original native file format. Specific software tools can have a built-in capacity to ensure the ability to read and use the file format of other modelers. A number of the larger modeling software companies are now developing suites of modeling and construction-related software tools that are quite interoperable amongst them. However, most of the BIM applications of modeling and their complementary software tools only address interoperability among themselves and not in relation to other vendors' applications (Grilo and Jardim-Goncalves, 2010).

2.3.4 BIM Benefit, Risks and Barriers

2.3.4.1 Benefit

Greater productivity and efficiency across the entire life cycle of any building is foremost reason for deploying new technology. It is widely accepted that the primary benefit of BIM is the ability to resolve physical interference problem virtually to eliminate the need to address these problems at far greater risk and expense during construction (Smith and Tardif, 2009). BIM is very well suited to reducing ambiguity and uncertainty throughout the building design and construction process.

BIM is a catalyst for reducing industry's fragmentation and improving its efficiency and effectiveness and lowering its high costs of inadequate interoperability. BIM distributed information model paradigm fosters greater market demand for interoperability – the seamless, reliable exchange of digital data which in turn creates the market conditions for a greater array of specialized software tools (Smith and Tardif, 2009). BIM can help improve the quality and accuracy of financial forecasts, which can lead to greater productivity and profit (Smith and Tardif, 2009). BIM is an enabling technology that could potentially improve communication among business partners, quality of information available for decision-making, quality of service delivered, and reduce cycle time and cost at every stage in the life cycle of a building (Smith and Tardif, 2009).

Autodesk conducted a web survey to examine the top 5 most misconceptions about BIM, and the result revealed that BIM brings productivity increase after an average of 3 to 4 months with an average productivity loss of 25–50% during the initial training period, easier accessibility than general CAD application, enhanced workflow after training period finish, great value and benefit for owners, designers and contractors, a way of reducing risk of design errors and enabling communication and coordination among the project team (Autodesk, 2007). Figure 7 is the comparision of the time spent on different stages of the design process for two projects of the similar size and scope using Revit Architecture versus traditional CAD tools done by Lott + Barber Architects firm to show time reduction and productivity boosts with BIM (Autodesk, 2007).

Task	CAD (hours)	BIM (hours)	Hours saved	Time savings
Schematic design	190	90	100	53%
Design development	436	220	216	50%
Construction documents	1023	815	208	20%
Checking and coordination	175	16	159	91%
Totals:	1,824	1,141	683	

Figure 7 BIM Enables Lott + Barber to Save Time and Increase Productivity (Autodesk, 2007)

Autodesk also addressed that applications of BIM provide immediate competitive advantages, better coordination and quality, and can contribute to higher profitability for architects and the rest of the building team from conceptual studies through the most detailed construction drawings and schedules (Autodesk, 2007), and change the way of working process in that BIM rebalance team efforts to design phases, avoid over documenting, use more visualizations for client communication and offer some expanded services such as energy usage, quantity takeoffs, and specification coordination (Autodesk, 2007), and lead to more engaged teams, more informed decision-makings and better coordination (Autodesk, 2007).

2.3.4.2 Risks

The first legal risk of BIM is to determine ownership of the BIM data and to know how to protect it through copyright and other laws. If the owner is paying for the design, then the owner may feel entitled to own it, but if team members are providing proprietary information for use on the project, their propriety information needs to be protected as well. Thus, there is no simple answer to the question of data ownership; it requires a unique response to every project depending on the participants' needs (Thompson, 2001). When project team members other than the owner and AE contribute data that is integrated into the BIM, licensing issues could arise. Licensing issues could also arise if the vendor's design was produced by a designer and not licensed in the location of the project (Thompson and Miner, 2007).

Another risk issue to address is about who will control the entry of data into the model and be responsible for any inaccuracies in it. Taking responsibility for updating BIM data and ensuring its accuracy entails a great deal of risk. Requests for complicated indemnities by BIM users and the offer of limited warranties and disclaimers of liability by designers will be essential negotiation points that need to be resolved before BIM technology is utilized. It also requires more time spent in inputting and reviewing BIM data, which is a new cost in the design and project administration process. Although these new costs may be more than offset by efficiency and schedule gains, they are still a cost that someone on the project team will have to bear (Thompson and Miner, 2007). The architect, engineers and other contributors of the BIM process look to each other in an effort to try to determine who should take responsibility for the raised problems. If disagreement ensues, the lead professional will not only be responsible as a matter of law to the claimant but may have difficulty proving faults with others such as the engineers (Rosenburg, 2007).

As the dimensions of cost and schedule are layered onto the 3D model, responsibility for the proper technological interface among various programs becomes an issue. Many sophisticated contracting teams require subcontractors to submit detailed CPM schedules and itemized cost breakdowns by line items of work prior to the start of the project. The general contractor then compiles that data, creating a master schedule and cost breakdown for the entire project. In cases where the data is incomplete or is submitted in a variety of scheduling and costing programs, a general contractor or construction manager must re-enter and update a master scheduling and costing program. That program may be a BIM module or another program that will be integrated with the 3D model. At present, most of these project management tools and the 3D models have been developed in isolation. Responsibility for the accuracy and coordination of cost and scheduling data must be contractually addressed (Thompson and Miner, 2007).

2.3.4.3 Barriers

Arno Schlueter proposed that the biggest obstacle for architects to adopt BIM methods is the tentative use of BIM by other industry partners such as engineering firms (Schlueter and Thesseling, 2009). Autodesk addressed that barriers to wider adoption of BIM in the building industry include fragmentation and calcified processes, lack of data interoperability between software applications, the need for well-defined transactional business process models, the requirement that digital design data can be computable and the need for well-developed practical strategies for the purposeful exchange of meaningful information between many tools applied to industry process (Autodesk, 2007).

Many building industry professionals, accustomed to the fragmented nature of the building industry, remain unaware of the worldwide efforts being made to address the problems of workflow and building information for the lack of resources or incentives to fund the research or the ability to influence innovation in architectural, engineering, or product design (Smith and Tardif, 2009). To restrain a new way of doing business with outdated business relationships would be not only unwise but also costly, and would keep us from realizing the full potential of BIM (Smith and Tardif, 2009). BIM authoring tools – the large, robust application that are used to create and compile most of the information contained in a building information model are often perceived as costly to purchase and deploy. Business leaders have a tendency to evaluate technology on the basis of its acquisition cost rather than its full implementation cost and full revenue-generating potential (Smith and Tardif, 2009), which hampers the full adoption of BIM. Actually, the cost of the software is only a small fraction of the total investment in BIM (Smith and Tardif, 2009).

2.3.5 BIM in Construction Material Procurement

A purpose-built BIM can feed the structural fabrication process and enable a fully-digital, design-to-manufacturing process which makes reusing the design model inherently more efficient and discrepancies between the design and fabrication models are eliminated. The BIM fabrication model does not necessary represent as-built conditions and it can still change during project erection process, but it can contain more details than the structural model to be more useful in interference checking especially for building types or applications where space is extremely tight (Autodesk, 2007).

Using the design models directly for fabrication will create a natural feedback loop between fabricators and designers and bring fabrication considerations forward into the building design process. Sharing the design model with fabricators for bidding will shorten the bid cycle and lead to more uniform bids based on BIM. The coordination between the fabricated materials and other components will reduce the amount of onsite issues and drive down the rising cost of material and component erection (Autodesk, 2007). The material quantity, specification and property description will be more accurate and detailed, miscommunication about material procurement information will be reduced, material inspection time will decrease and material procurement cost will be cut down if BIM is applied in construction material procurement process.

However, literature review reveals that very few efforts have been directed to the application of BIM for e-procurement (Grilo and Jardim-Goncalves, 2011). Grilo and Jardim-Goncalves described how the BIM combined with the Model-Driven Architecture, Service-Oriented Architecture, and Cloud Computing may challenge e-procurement in the AEC sector, and presented the application of a SOA4BIM framework in the context of e-procurement and described an industrial research case study for validation of the proposed approach in the conception and design phases of building/construction projects (Grilo and Jardim-Goncalves, 2011).

Grilo and Jardim-Goncalves also addressed that the interoperability factor becomes even more acute if there is a goal of e-platforms to enhance the collaborative functions of BIM with traditional e-procurement and e-sourcing functions, where building product objects (such as windows, doors, plumbing, etc.) besides parametric 3D model information must be coupled with transactional information, as in Request for Proposal (RFP), Order and Invoice (Grilo and Jardim-Goncalves, 2010). As each building/engineering project tends to be unique, it is critical to the success of e-procurement that the BIM approach considers the use of universal interoperability standards for the various dimensions, i.e., not only in the e-tendering, e-ordering, e-invoicing or e-catalogues, but also on product and process models (Grilo and Jardim-Goncalves, 2011).

2.3.6 BIM in Material Quantity Takeoff and Cost Estimate

A purpose-built BIM solution features computable building information that enables a model to be understood by a computer as a building by three-dimensional, real-time, dynamic building modeling software in building design and construction (Autodesk, 2007). One potential benefit of exchanging BIM data between an architect and a contractor is a reduction in the time needed for the quantity takeoff.

Conceptually, construction design, shop drawing preparation, quantity takeoff and material procurement are a series of related process. Historically, accurate quantity takeoff was the responsibility of constructors. The constructor was solely responsible for the material quantities (Smith and Tardif, 2009). In traditional cost estimating method, material quantity takeoff is done by human from the CAD drawings, which introduces the more potential for human errors and propagates any inaccuracies and involves much waste and inefficiency. When the designers or engineers change the information in any view, traditional material method requires lots of working time and human labor to make modification on all views, schedules, material takeoff, and so on. With BIM, building material quantity takeoff information, specifications, referenced standards, warranties and operational requirements can be extracted from a BIM model created by design professionals. An architect might understandably have concern that a contractor will rely on the model and hold the architect accountable for material quantities. Architects can use the information within their design model to easily double check estimating quantities, which facilitates concurrent estimating during the design process (Autodesk, 2007).

With BIM, when the design or shop drawing changes the information in any view, all views, schedules, material quantity takeoff, and so on will update automatically, and information across all representations of the project is reliable, coordinated, and internally consistent (Autodesk, 2007). BIM offers significant advantages over traditional drawing-based systems by minimizing manual takeoffs and facilitating improved communication, coordination and collaboration, time and cost reduction and resulting in less misunderstanding between owners, designers, engineers, contractors, fabricators, facility operators across the whole construction industry in material quantity takeoff and cost estimate process, which will also provides more accurate material cost standard to evaluate the quotes from potential suppliers in the tendering and bidding process. Reducing the quantification efforts means that contractors can more effectively apply their time and knowledge to higher value estimating activities including construction assemblies, generating pricing, factoring risks, and so forth (Autodesk, 2007).

2.3.7 BIM Software

2.3.7.1 BIM Software Vendors

Presently, Autodesk, Bentley, Graphisoft and Nemetschek are four BIM construction software providers in construction industry. BIM authoring tools include Autodesk Revit, Bentley Architecture, Graphisoft ArchiCAD and Nemetschek Vectorworks (Smith and Tardif, 2009). These four companies have their own respective BIM software products and graphics development platform. Table 2 displays the comparision of these four main BIM authoring tools.

Product Name	**Autodesk Revit**	**Bentley MicroStation**	**Graphisoft ArchiCAD**	**Nemetschek Vectorworks**
Developer	Autodesk/ www.autodesk.com	Bentley/ http://www.bentley.com/en-US/	Graphisoft/ http://www.graphisoft.com/	Nemetschek/ http://www.nemetschek.net/
Latest Version Released	Revit Architecture/MEP/Structure 2011	MicroStation V8*i*	ArchiCAD 14	VectorWorkers 2011

Open SDK and API Availability	Yes (Extensive .NET code samples and documentation and directions of use of API)	Yes	Yes	Yes
Development Tools	.NET compliant language including VB.NET, C#, and managed C++.	MicroStation Development Language (MDL) for seamless integration of applications with MicroStation and Bentley products/ C, C++, C#, and Visual Basic.	Windows or Macintosh platforms/C or C++ language programming	Microsoft Visual C++ for Windows development and/or Apple Xcode for Macintosh development
Application in BIM based Quantity Takeoff Software	Yes	No	No	No

Table 2 Comparision of BIM Software Vendors

2.3.7.2 BIM and Non-BIM based Quantity Takeoff / Cost Estimate Software

Presently, popular commercial non-BIM based and BIM based construction material quantity takeoff and cost estimate software is listed in Table 3 respectively:

	Product Name	Model Input
BIM based Software	Autodesk Quantity Takeoff (QTO)	AutoCAD, Revit Architecture, AutoCAD Civil 3D, non_intelligent CAD data, image formats .jpg and .tif.
	Innovaya Visual Quantity Takeoff	Autodesk Revit, AutoCAD Architecture/MEP and Tekla Structure
	Tocoman Quantity Takeoff	Autodesk Revit, ArchiCAD, Tekla Structure
	Vico Takeoff Manager	Autodesk Revit/Tekla/ArchiCAD/CAD-Duct
Non-BIM based Software	Bid4Build	.pdf/.tiff/.jpeg/Full graphics capability
	QuestMX	.pdf/.tif/.gif/.jpg/.bmp/CAD formats
	PlanSwift	.tif/.pdf /- Adobe/.dxf/.dwf/.dwg/- AutoCAD/.pln/.jpg
	On-Screen Takeoff	.tif/.pdf/.cal/.cpc/.plt/.pln/.dwf/.dgn/.me, /drw/.bla/.dxf/.pct/.dwg/.ose/.cgm/.hpg

Table 3 BIM based and Non BIM based Material Quantity Takeoff Software

Comparison of specific features of popular BIM construction material quantity takeoff and cost estimate software is listed in Table 4:

Product Name	**Quantity Takeoff (QTO)**	**Innovaya Visual Quantity Takeoff**	**Tocoman Quantity Takeoff**	**Vico Takeoff Manager**
Developer/ Producer	Autodesk/ www.autodesk.com	Innovaya/ http://www.innovaya.com/	*TocoSoft Oy/* http://www.tocoman.se/	Vico Software, Inc./ www.vicosoftware.com
New Version Released	Quantity Takeoff 2011	Innovaya Visual Quantity Takeoff/ Design Estimating	Tocoman iLink 2010 / Express 2010	Vico Cost Planner and Schedule Planner
Compatible Design Model	AutoCAD/Revit Architecture/ AutoCAD Civil 3D/Non_intelligent CAD data/.jpg/.tif.	Autodesk Revit/ AutoCAD Architecture/MEP /Tekla Structure	Autodesk Revit/ ArchiCAD/Tekla Structure	Autodesk Revit/ Tekla/ArchiCAD/CAD-Duct
Cost Data Output	Microsoft Excel /Word/TXT/ Comma Separated Variable (CSV)	MS Excel/PDF	MS Excel/Timberline/Autodesk Navisworks	MS Excel
Software Feature	- Both Manual quantity takeoff and automatic quantity takeoff - Unlimited component sub-assemblies for a virtually infinite level of detail - Options for Cost Database	- Allow Revit objects to be assigned with RSMeans Assembly Cost Database - Cost estimating with no pre-mappings required	- Search results and quantities can be exported into Autodesk Navisworks.fr - Smart 3D visualizations	- Location - based quantity takeoff - Flexibly organize the quantity takeoff way

Table 4 Specific Features of Commercial BIM based Software

2.4 Material Supplier Performance Evaluation

2.4.1 The Necessity to Incorporate Supplier Performance Evaluation Function

Supplier performance evaluation has been important in operational decisions, involving decisions of selecting which vendors to employ, as well as decisions with respect to quantities to order from each vendor. The reasons to incorporate supplier performance evaluation function in BIM integrated with e-commerce software solutions include the following 4 aspects:

- Supplier performance evaluation is the premise and important procedure in material supplier selection, supplier awarding and electronic material procurement process. Therefore, supplier performance evaluation should be one function incorporated into BIM integrated with e-commerce material quantity takeoff and cost estimate software solutions, and it is one important part of BIM integrated with e-commerce material procurement framework.

- BIM integrated with e-commerce material system solutions provide one innovative approach and improved way for material procurement process. Supplier performance evaluation based on BIM integrated with e-commerce material system solutions will be more accurate and precise, and it will provide objective and better reference for future supplier selection decision-making in material procurement process.

- Present famous large commercial e-commerce websites such as www.amazon.com, www.ebay.com and www.taobao.com all allow buyer customers to evaluate supplier performance based on definite standards within a specific time period after each procurement process finishes. Performance evaluation records will be the historical supplier performance evaluation data, and help buyer customers to select suppliers in the next procurement process and assist seller customers to improve performances and make more profits based on the performance evaluation results from the buyer customers.

- BIM integrated with e-commerce material procurement and supplier performance evaluation is interrelated process and can't be isolated, so BIM integrated with e-commerce material procurement system should incorporate material supplier performance evaluation function.

2.4.2 Performance Evaluation Criteria

Substantial research literatures have explored the subject of using decision tools for supplier selection and evaluation in supply chain management over the decades (Aksoy and Ozturk, 2011). Willis classified supplier performance evaluation models into categorical, weighted points, and cost ratio approaches (Willis, 1993).

Vonderembse and Tracey presented supplier evaluation criteria from five aspects including plant stoppages decreased, percent on-time delivery increased, timely material deliver, in-transit damage reduced and high quality incoming parts (Vonderembse and Tracey, 1999). Ulubeyli and Manisali propose key aspects for detailed subcontractor selection matters including subcontractor resources of main contractors, some informal attributes, the selection timing and types, subcontractor usage rates, selection guides and shortlists, and decision-makers of the subcontractor choice (Ulubeyli and Manisali, 2010). Kannan and Tan present assessment criteria to study the importance of these criteria of American manufacturing company for items to be used in products (Kannan and Tan, 2002). These criteria include quality level, service level, correct quantity, on-time delivery, price/cost of product, use of electronic data interchange, willing to share sensitive information, presence of certification or other documents, the flexibility to respond to unexpected demand changes, communication skill/systems, quick response time in case of emergency , problem or special request, willingness to change their products and services to meet your changing needs and willingness to participate in your firms new product development and value analysis (Kannan and Tan, 2002). Wu and Blackhurst proposed an augmented DEA approach to evaluate supplier performance from Quality, Price, Delivery and Cost reduction performance aspects (Wu and Blackhurst, 2009). Chen proposed structured methodology for supplier selection and evaluation in supply chain with criteria and indicators from competition and organization factors (Chen, 2011), which are listed in Figure 8:

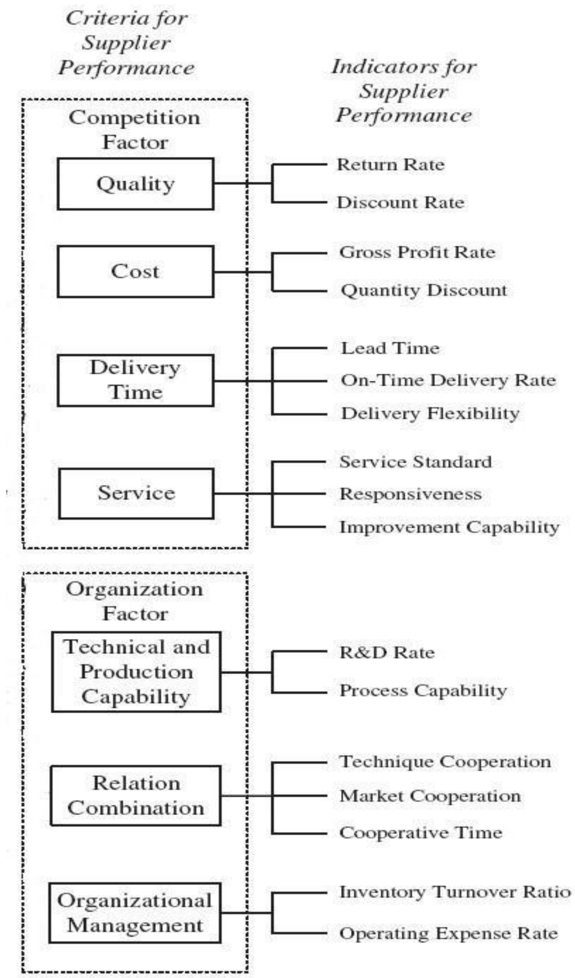


Figure 8 Chen's Supplier Performance Evaluation Criteria and Indicators (Chen, 2011)

2.4.3 Performance Evaluation Methods

Several different methods for evaluating supplier performance have appeared in the literatures, such as the categorical method, the weighted point method, the cost ratio method and the weighted point method using a performance matrix (Aksoy and Ozturk, 2011). Pan and Lee study supply and demand behavior, and establish a hierarchical model and develop a performance evaluation method based on Supply Chain Operation Reference Model of Supply Chain Council (Pan and Lee, 2011). A comprehensive evaluation methodologies and literature citations are shown in Table 5:

Evaluation Methodology	Source
Analytical hierarchy/network process	Chan (2003); Sevkli (2007)
Weighted Scoring Methods	Lambert (1993)
Human Judgment Models	Patton (1996)

Mathematical Programming	Cakravastia and Takahashi (2004)
Multi-Criteria Programming	Sarkis and Talluri (2002)
Data Envelopment Analysis	Sevkli (2007)
Matrix Method	Gregory (1986)
Discrete Choice Analysis Experiments	Sarkis (2000)
Total Cost of Ownership	Degraeve (2000)
Statistical Analysis	Chen (2006)
Principle Component Analysis	Patroni and Braglia (2000)
Neutral Network	Wei and Zhang (1997)
Interpretive Structural Modeling	Mandal and DeshMukh (1994)
Game Models	Talluri and Narasimham (2003)
Grey Additive Ratio Assessment (ARAS-G)	Turskis and Zavadskas (2010)

Table 5 Supplier Performance Evaluation Methodologies and Literature Citations (Ross and Buff, 2009)

However, current supplier selection and evaluation models have the following shortcomings: Excessive focus on problem solving support related solely to the evaluation and assessment phase; lack of integration between data-based methods and experience-based techniques into a coherent framework; excessive focus on performance; less emphasis on strategic issues; shortcomings in dealing with qualitative, imprecise and ambiguous data; local focus rather than global; static analysis; difficulty to customize for specific situations (Landoli and Shore, 2004)

2.5 System Integration

In information technology, system integration is the process of linking together different computing systems and software applications physically or functionally. System integration brings together discrete systems utilizing a variety of techniques such as computer networking, enterprise application integration, business process management or manual programming (Moore, 1982).

Vertical Integration is the process of integrating subsystems according to their functionality by creating functional entities (Lau, 2005). The benefit of this method is that the integration is performed quickly and involves only the necessary vendors and is cheaper in the short term.

Star Integration is a process of integration of the systems where each system is interconnected to each of the remaining subsystems. From the feature perspective, this method is often preferable, due to the extreme flexibility of the reuse of functionality (Gold-Bernstein and Ruh, 2005). One disadvantage of this integration method is that time and cost needed to integrate the systems increase exponentially when adding additional subsystems. In a case where the subsystems are exporting heterogeneous or proprietary interfaces, the integration cost can substantially rise.

Horizontal Integration is the integration method in which a specialized subsystem is dedicated to communication between other subsystems. Horizontal Integration is capable of translating the interface into another interface and allows cutting the costs of integration and provides extreme flexibility (Gold-Bernstein and Ruh, 2005).

BIM based quantity takeoff and cost estimate software has the potential to be integrated with E-Commerce software system to facilitate cooperative work and benefit material procurement in construction quantity takeoff, cost estimate, material procurement and supplier evaluation process.

3 Proposed BIM Integrated with E-Commerce Framework in Material Procurement Process

3.1 Proposed Framework for BIM Integrated with E-Commerce Application

Based on the research about BIM and E-Commerce in construction material quantity takeoff, cost estimate and material procurement, supplier performance evaluation, system integration and the generic SOA4BIM framework presented by Grilo (Grilo and Jardim-Goncalves, 201), a primary framework of BIM integrated with E-Commerce in material quantity takeoff, cost estimate, material procurement and supplier performance evaluation application is proposed in Figure 9:

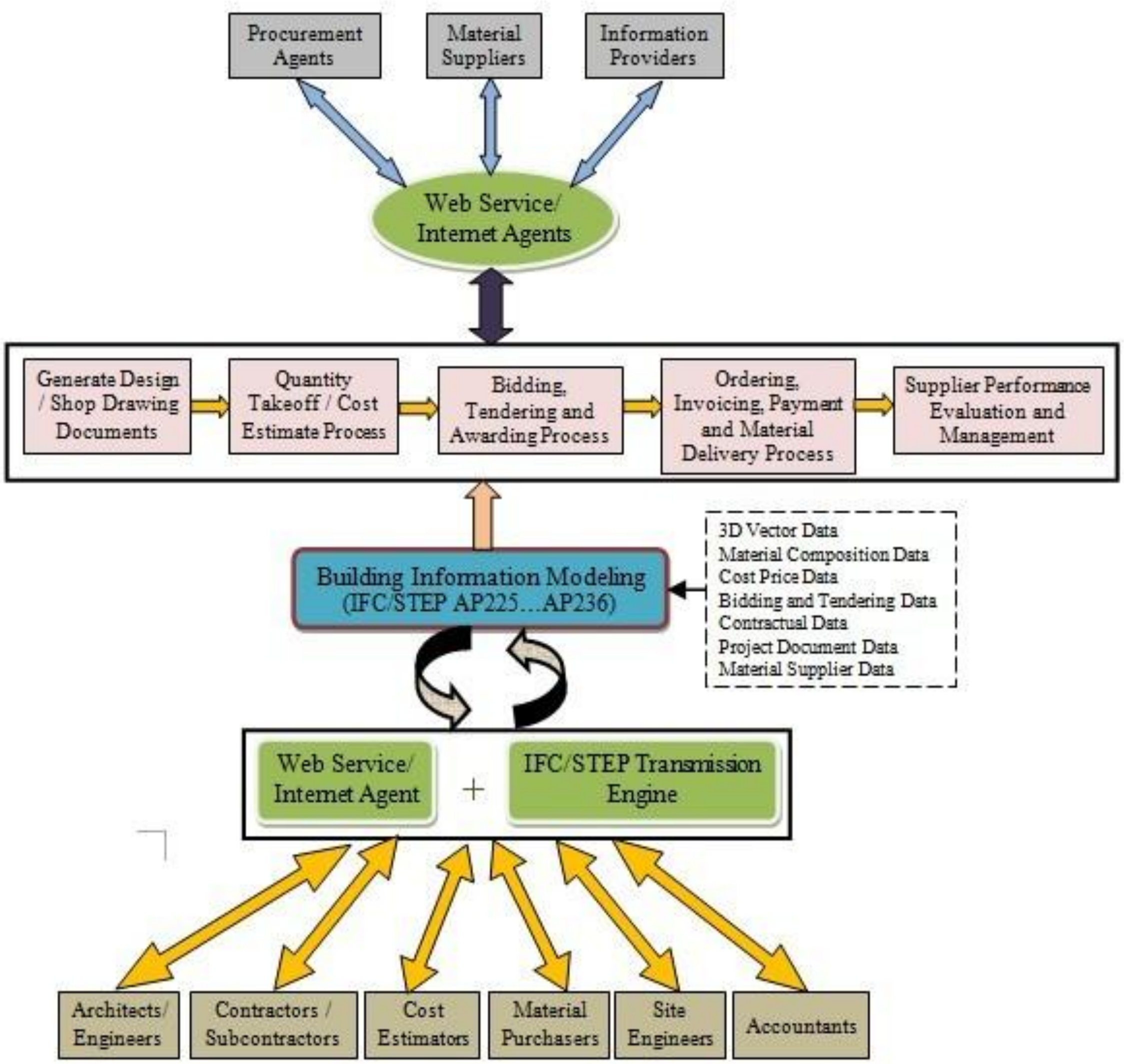


Figure 9 Framework of BIM integrated with E-Commerce Application

In this framework, BIM is the key process and supporting platform to standardize and integrate 3D vector data, material composition data, cost price data, bidding and tendering data, contractual data, project document and information data, material supplier data. This standardized and integrated process is achieved through the operations of Web Service and Internet Agent tools and IFC/STEP standard transmission engine, and architect/engineers, contractors/subcontractors, cost estimators, material purchasers, site engineers and accountants are the main process participants. Material quantity takeoff, cost estimate, bidding and tending, procurement, and supplier evaluation and management process are based on BIM and E-Commerce platform. Material suppliers, procurement agents and information providers take part in this series of process through Web Service/Internet Agent.

3.2 Proposed BIM Platform and Cost Data Source

After the comparison of different BIM software, Autodesk Revit platform is chosen as BIM development platform for material quantity takeoff. Autodesk Revit is presently the most popular BIM software platform, and has the most worldwide BIM software users. Autodesk Revit has released comprehensive Application Programming Interface (API) and Software Development Kit (SDK), which are convenient for developers to make secondary development based on Revit platform to generate quantity takeoff report. BIM design document could be generated, imported, modified or saved in Autodesk Revit platform.

RSMeans Unit Price material cost data is adopted as cost price data source. Quantity takeoff results from BIM design documents in Revit platform will be linked with RSMeans Unit Price material cost data to generate cost estimate report. This solution has advantages over commercial BIM based quantity takeoff software such as QTO, Innovaya Visual Quantity Takeoff, Tocoman Quantity Takeoff and Vico Takeoff because none of these commercial software links quantity takeoff data from BIM design documents with RSMeans Unit Price material cost data. Cost estimate information generated in this software module will potentially have better accuracy over traditional cost estimate methods and will provide a better cost standard for the future supplier quotes evaluation and supplier selection.

3.3 Proposed Supplier Performance Evaluation Model

Supplier performance evaluation and Information Management is one important function module of the above framework. Based on comprehensive literature review and considering the feasibility and practicability for user evaluation, the author presents ten main evaluation criteria including Cost(C), Quality(Q), Delivery(D), Service(S), Assurance of Supply(AS), Overall Ability(OA), Payment Terms(PT), Information Sharing(IS), Reputation(R) and Buyer-Supplier Relationship(BSR). Each evaluation criterion also comprises several performance indicators. In order to emphasize the importance of BIM and satisfy practical e-procurement process requirement, the "Conform to BIM Standard" is a performance indicator in the Evaluation Criteria of "Overall Ability". All evaluation criteria list and performance indicator list are shown in Table 6 and Table 7 respectively:

Evaluation Criteria	***Weight Coefficient (1 to 5)***
Cost (C) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐
Quality (Q) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐
Delivery (D) (Wang and Guo, 2007)	1☐ 2☐ 3☐ 4☐ 5☐
Service (S) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐
Assurance of Supply (AS) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐
Overall Ability(OA) (Chan, 2003)	1☐ 2☐ 3☐ 4☐ 5☐
Payment Terms(PT) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐
Information Sharing (IS) (Kannan and Tan, 2002)	1☐ 2☐ 3☐ 4☐ 5☐
Reputation(R) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐
Buyer-Supplier Relationship (BSR) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐

Table 6 Supplier Performance Evaluation Criteria List

Evaluation Criteria	***Performance Indicators***	***Weight Coefficient (1 to 5)***	***Choice Value (1 to 5)***
Cost (C)	Total Cost (TC) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐	1☐ 2☐ 3☐ 4☐ 5☐
	Price Stability (PS) (Lam and Tao, 2010)	1☐ 2☐ 3☐ 4☐ 5☐	1☐ 2☐ 3☐ 4☐ 5☐
	Discount Rate (DR) (Chen, 2011)	1☐ 2☐ 3☐ 4☐ 5☐	1☐ 2☐ 3☐ 4☐ 5☐

Quality (Q)	Return Rate (RR) (Chen, 2011)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Failure Prevention (FP) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Appearance and Function (AF) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Delivery (D)	Lead Time (LT) (Chen, 2011)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	On-Time Delivery (OTD) (Chen, 2011)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Delivery Flexibility (DF) (Chen, 2011)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Service (S)	Service Standard (SS) (Chen, 2011)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Technical Assistance & Support (TAS) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Cooperation & Communication(CC) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Assurance of Supply (AS)	Capability(C) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Reliability(R) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Flexibility(F) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Overall Ability (OA)	Technical Ability (TA) (Chan, 2003)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Conform to BIM Standard (CBS)	1 ☐ 2 ☐ 1 ☐ 1 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

	Management Ability (MA) (Chan, 2003)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Production Ability (PA) (Chan, 2003)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Payment Terms (PT)	Standard Payment (SP) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Payment Flexibility (PF) (Lam and Tao, 2010)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Information Sharing (IS)	Use of Electronic Data Interchange (UEDA) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Willing to Share Sensitive Information (WSSI) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Reputation (R)	Commitment to Quality (CQ) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Ability to Meet Due Date (AMDD) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Commitment to Continuous Improvement (CCI) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Honesty Communication (HC) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
Buyer-Supplier	Geographical	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Relationship (BSR)	Compatibility (GC) (Kannan and Tan, 2002)		
	Culture Match (CM) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
	Past and Future Relationship (PFR) (Kannan and Tan, 2002)	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Table 7 Supplier Performance Indicators List

Based on the literature review of the performance evaluation methods, a simple Weight Coefficient method is designed and adopted in this framework. Each evaluation criterion is provided with a weight coefficient from any number between 1 and 5. Weight Coefficient 1 represents that this criterion is totally unimportant. Weight Coefficient 2 represents that this criterion is fairly unimportant. Weight Coefficient 3 represents that this criterion is neither unimportant nor important. Weight Coefficient 4 represents that this criterion is fairly important. Weight Coefficient 5 represents that this criterion is very important.

Each performance indicator is provided with a weight coefficient and choice value from any number between 1 and 5. Weight Coefficient 1 represents that this performance indicator is totally unimportant. Weight Coefficient 2 represents that this performance indicator is fairly unimportant. Weight Coefficient 3 represents that this performance indicator is neither unimportant nor important. Weight Coefficient 4 represents that this performance indicator is fairly important. Weight Coefficient 5 represents that this performance indicator is very important. Choice Value 1 represents that the supplier’s performance in this performance indicator is totally unsatisfactory. Choice Value 2 represents that the supplier’s performance in this performance indicator is fairly unsatisfactory. Choice Value 3 represents supplier’s performance in this performance indicator is neither unsatisfactory nor satisfactory. Choice Value 4 represents that the supplier’s performance in this performance indicator is fairly satisfactory. Choice Value 5 represents that the supplier’s performance in this performance indicator is very satisfactory.

In this framework, Single Performance Indicator Value (SPIV) is calculated by multiplying each Choice Value (CV) and Weight Coefficient Value of this Performance Indicator (PIV). Single Evaluation Criterion Value (SECV) is the sum value of SPIV belonging to this evaluation criterion. Total Evaluation Criterion Value (TECV) is the sum value of multiplying each SECV by the Weight Coefficient Value of this Evaluation Criterion (ECV). The following 7 calculation functions could be applied to deal with supplier performance evaluation records and the calculation results could be as the indicator to measure each material supplier’s performance.

- **Function 1:** Single Performance Indicator Value (SPIV) = ∑ ((Choice Value of the Performance Indicator, CV) * (Weight Coefficient Value of the Performance Indicator, PIV))

- **Function 2:** Single Evaluation Criterion Value (SECV) = ∑ (Single Performance Indicator Value, SPIV)

- **Function 3:** Total Evaluation Criterion Value (TECV) = ∑ ((Single Evaluation Criterion Value, SECV) * (Weight Coefficient Value of the Evaluation Criterion, ECV))

- **Function 4:** Average Choice Value (ACV) = (∑ CV) / N

- **Function 5:** Average SPIV (ASPIV) = (∑ SPIV) / N

- **Function 6:** Average SECV (ASECV) = (∑ SECV) / N

- **Function 7:** Average TECV (ATECV) = (∑ TECV) / N

N represents the number of authorized evaluators that have completed the performance evaluation of one supplier's performance in one specific project. N is also the total number that has been taken into SUM (∑) calculation in from Function 4 to Function 7. CV (ACV), SPIV (ASPIV), SECV (ASECV) or TECV (ATECV) could be calculated to indicate and evaluate one supplier's performance in one project, or be compared to rank multiple suppliers' performance in one project, or rank one supplier's performance in multiple projects. All the evaluation records, data and calculated results could be saved to system database and serve as reference data in the future decision-making process of potential supplier selection.

4 Software System Design and Development

Software design and development needs to take the following factors into consideration: ease of installation and configuration, low cost, ease of connection and integration, ability to integrate external systems and information, and customizable access to information and applications (Cheng and Law, 2010). Considering the technical complexity, difficulty and time restraint of the proposed BIM and E-Commerce software application framework proposed in Chapter 3, the author designed and developed a simple elementary version of the BIM integrated with E-Commerce material procurement and supplier management system as the first step to implement this framework.

4.1 System Function Design

This system performs the following functions:

- **Design Document Management**: Importing new BIM based design document to this system, or creating new, or saving, or modifying, or deleting existing BIM based design document in the system.

- **Material Quantity Takeoff:** Extracting the exact quantity data of different material members from design documents, and saving these quantity takeoff reports to database.

- **Material Cost Estimate:** Displaying material cost information and generating material cost estimate reports by linking the results of quantity takeoff results and cost criteria (RSMeans Unit Price cost data), and save these cost estimate reports to database.

- **Tendering，Bidding and Awarding Management:** Using the e-commerce tools to manage bidding, tendering, awarding and document information in the processes of publishing material bidding information, receiving and evaluating all quotations from suppliers, negotiation and signing the final contract with suppliers (e-tendering, e-bidding, and e-awarding). All material specification in this process is described with BIM.

- **Transaction History Management:** Recording and managing all material transaction history activities, information and documents in the material transaction process which may include issuance of purchase order, receiving acknowledgement and invoice, delivery of goods, material inspections, payment (e-ordering, e-invoice and e-payment) and other activities.

- **Supplier Performance Evaluation and Information Management:** Recording the supplier information and making performance evaluation after all transactions concerning one supplier in one project finish to form a preliminary historical supplier performance evaluation system for each supplier. This will provide the reference for the decision-making in the future material supplier selections.

- **Project Document/Information Management:** Keeping and managing all the project information and electronic documents including Estimate Report, Request for Quotation (RFQ), Purchase Order (PO), Inspection Report, Invoice, Purchase Requisition (PR) and etc. in software system.

- **User Role and Safety Control:** Designing different system users and assigning user roles and access rights in this system according the practical responsibility division and project requirements in construction firms. Users include designers/engineers, contractors, estimators, purchasers, accountants, suppliers and site engineers. Users' access rights vary from no access right, to viewing, adding, modifying, and deleting different system functions. Safety control is implemented by assigning user name and password and webpage access rights.

4.2 User Role Definition

User role definition includes two parts: user role and access right designation. User role is which types of different system users are able to operate this system. User access rights are the types of functions a specific user role could perform on this system. This system has been designed with the following user roles: Designers/Engineers, Contractors, Estimators, Purchasers, Site Engineers, Accountants, Suppliers and Anonymous. For a specific system function, five different access rights including No Access Right, View, Add, Delete and Modify have been chosen to be designated to different user roles. Table 8 displays each user role with different user rights.

User Roles	***System Functions***	***Right Designation***
Designers/ Engineers	Design Document Management	View, Add, Delete, Modify
	Material Quantity Takeoff	No Access Right
	Material Cost Estimate	No Access Right
	Tendering, Bidding and Awarding Management	No Access Right
	Transaction History Management	No Access Right
	Supplier Performance Evaluation and Information Management	No Access Right
	Project Documents/Information Management	View, Add, Delete, Modify
Contractors	Design Document Management	View, Add, Delete
	Material Quantity Takeoff	View, Add, Delete, Modify

	Material Cost Estimate	View, Add, Delete, Modify
	Tendering, Bidding and Awarding Management	View, Add, Delete, Modify
	Transaction History Management	View, Add, Delete, Modify
	Supplier Performance Evaluation and Information Management	View, Add, Delete, Modify
	Project Documents/Information Management	View, Add, Delete, Modify
Estimators	Design Document Management	View
	Material Quantity Takeoff	View, Add, Delete, Modify
	Material Cost Estimate	View, Add, Delete, Modify
	Tendering, Bidding and Awarding Management	View, Add, Delete, Modify
	Transaction History Management	View, Add
	Supplier Performance Evaluation and Information Management	View
	Project Documents/Information Management	View, Add, Delete, Modify
Purchasers	Design Document Management	View
	Material Quantity Takeoff	View
	Material Cost Estimate	View
	Tendering, Bidding and Awarding Management	View
	Transaction History Management	View, Add, Delete, Modify
	Supplier Performance Evaluation and Information Management	View, Add
	Project Document/Information Management	View, Add, Delete, Modify
Site Engineers	Design Document Management	View
	Material Quantity Takeoff	View
	Material Cost Estimate	View
	Tendering, Bidding and Awarding Management	View, Add, Delete, Modify
	Transaction History Management	View, Add, Delete, Modify
	Supplier Performance Evaluation and Information Management	View, Add
	Project Document/Information Management	View, Add, Delete, Modify
Suppliers	Design Document Management	No Access Right

	Material Quantity Takeoff	No Access Right
	Material Cost Estimate	No Access Right
	Tendering, Bidding and Awarding Management	View, Add
	Transaction History Management	View
	Supplier Performance Evaluation and Information Management	View
	Project Document/Information Management	View, Add
Anonymous	Design Document Management	No Access Right
	Material Quantity Takeoff	No Access Right
	Material Cost Estimate	No Access Right
	Tendering, Bidding and Awarding Management	View
	Transaction History Management	No Access Right
	Supplier Performance Evaluation and Information Management	No Access Right
	Project Document/Information Management	View
Accountants	Design Document Management	View
	Material Quantity Takeoff	View
	Material Cost Estimate	View
	Tendering, Bidding and Awarding Management	View
	Transaction History Management	View, Add, Delete, Modify
	Supplier Performance Evaluation and Information Management	View, Add
	Project Document/Information Management	View, Add, Delete, Modify

Table 8 System User Role with Corresponding Access Rights

4.3 System Structural Design

This system is designed to develop and operate on BIM Platform, E-Commerce Platform and Database.

- **BIM Platform:** This platform is designed to implement model import, addition, view, modification or deletion, material quantity takeoff and cost estimate functions.

- **E-Commerce Platform:** This platform is adopted to implement bidding, tendering and awarding (BIM based) management, transaction history management, project document (BIM based) and information management, and supplier performance evaluation and information management.

- **Database:** This system is designed to include 2 main databases. One is BIM graphics and material composition database provided by Autodesk Revit. The other database contains all information including project document and information, bidding, tendering and awarding information, transaction history information, supplier evaluation and information records, cost criterion information, quantity takeoff and cost report information, and system user role and access right information.

This system is primarily designed to be developed with a mixed Client/Server and Browser /Server mode.

- **Client/Server Mode:** This mode is mainly adopted for user operations including BIM design document import, view, modification and deletion, material quantity takeoff and cost estimate reports.
- **Browser/Server Mode:** This mode is mainly adopted for user operations including bidding, tendering and awarding (BIM based) management, transaction history management, supplier evaluation and information management, and project document (BIM based) and information Management.

This system adopts Vertical Integration because it is easy to execute. General system structure is displayed in Figure 10:

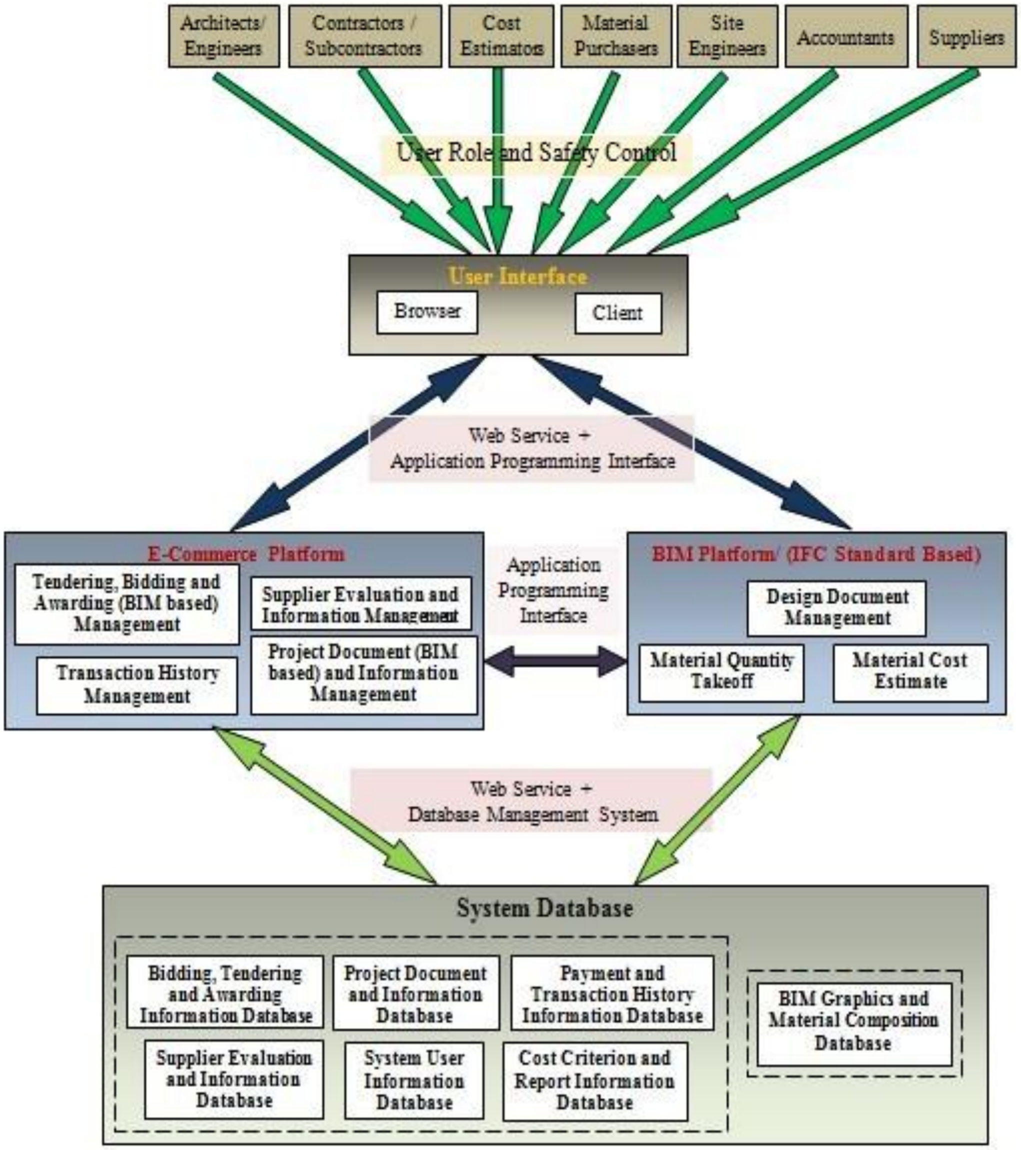


Figure 10 BIM Integrated with E-Commerce Software System Structure

System users include architects/engineers, contractors, cost estimators, material purchasers, site engineers, accountants, suppliers and anonymous. Different users enter the system after the validation of user name and password from user role and safety control function. Different types of users have different access rights, and could only view or operate different interface within their right range. The connection between user interface and e-commerce or BIM platform are Web Service and Application Programming Interface (API), the connection between E-Commerce and BIM platform is API, and the connections between e-commerce or BIM platform and database are Web Service and Database Management System.

4.4 System Module Design

This system is designed to comprise 4 main modules: User Interface Module, Application Program Module, Network Communication Module and Database Management Module. The following descriptions are descriptions of each module, module functions and potential key development technologies.

4.4.1 User Interface Module

- **Module Function:**
  - ✓ Provide related interfaces according to user role and access rights when different users log into the system and make operation.
  - ✓ Display plain and easy-to-use interface layout and operation hint.
  - ✓ Validate if each user input or operation is correct and proper.
  - ✓ Offer suitable error information or correction information to best ensure the consistency of user operation and system stability.
  - ✓ Convert user input or user command to related data information that application programs or database management programs could parse.
  - ✓ Send user input or user command and receive operation result from application programs or database management programs.
  - ✓ Parse the received operation results and display results in a proper way on user interface.

- **Potential Key Development Technologies:**
  - ✓ Interface Design / Safety Control / CSS / HTML/XML

4.4.2 Application Program Module

- **Module Function:**
  - ✓ Application Program comprises the core application logics of main system functions which include Design Document Management, Material Quantity Off, Material Cost Estimate, Tendering, Bidding and Awarding Management, Transaction History Management, Supplier Evaluation and Information Management, and Project Document and Information Management.
  - ✓ Receive and parse user command or input from user interface, or operation result data from data management module.
  - ✓ According to the type and content of parsed data, call the relevant application logics to execute relevant programs and generate corresponding intermediate result.
  - ✓ Encode and send the data containing the intermediate result to the user interface module or the database management module.

- **Potential Key Development Technologies:**
  - ✓ Objected-Oriented Programming / ASP.NET / IFC / Revit API

4.4.3 Network Communication Module

- **Module Function:**
  - ✓ Set up proper network data transmission mechanism and protocol based on TCP/IP.
  - ✓ Choose a suitable data encryption and deciphering algorithm.

- **Potential Key Technologies:**
  - ✓ Data Transmission Protocol / Encryption and Deciphering / Synchronous and Asynchronous Transmission / JavaScript / AJAX / Web Service

4.4.4 Database Management Module

- **Module Function:**
  - ✓ Manage tables, fields, values and relationships in all system databases.
  - ✓ Manage system user role, access rights and database safety, and prevent illegal login or operation of database.
  - ✓ Set up open or close network connection, watch network data transmission.
  - ✓ Accept network data transmission, parse command type or data information, and execute relevant database operation.
  - ✓ Return the data information of result by network with the format that the upper layer application program or user interface could parse.

- **Potential Key Technologies:**
  - ✓ ADO.NET / Dynamic Link Library(DLL) / SQL/ Tran-SQL

4.5 System Database Design

Of the two databases in this system, BIM graphics and material composition database is provided by Autodesk Revit, connects with quantity takeoff and cost estimate interface and provides the foundation for quantity takeoff and cost estimate operation. The other database is SQL Server relational database and it contains all information including project document and information, bidding and tendering information, transaction history information, supplier evaluation and information records, cost criterion information, quantity takeoff and cost report information, and system user and access right information in 30 database tables. Figure 11 displays the 30 tables in the SQL Server database in this software system designed and developed by the author.

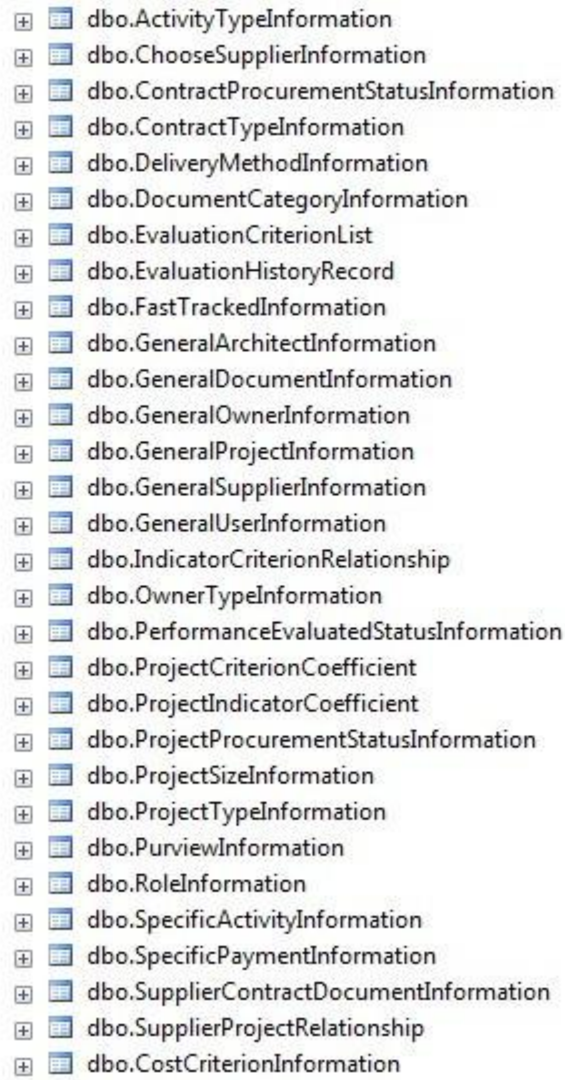


Figure 11 Table List of System SQL Server Database

Each table has been designed with a series of fields and data types. Each table has a unique primary key, which gets increment automatically when a new record is inserted into this table. The connection of different tables is through primary key and foreign key.

4.6 Required Development Technology and Schedule

Required technology and schedule for system development is listed in Table 9:

Time Line	Research Description	Detailed Research

Jan.1- Mar.31	More Extensive Literature Review	Construction Material Procurement Process and Responsibility of each Participants
		Features of BIM based Material Quantity Takeoff and Cost Estimate Software (QTO, Innoya, Tocoman, Vico Takeoff Manager)
		Supplier Selection Criterion and Methods
		E-Commerce Solution in Material Procurement
	Preliminary System Design	Finish Preliminary System Design Report
Apr. 1 - Apr.30	Detailed System Design	Finish Detailed System Design Report
	Extensive Relative Technology study	BIM Quantity Takeoff Development Tools (Autodesk Revit / Revit Development API) / IFC
		.NET Development (VS, C#, ASP.NET, ADO.NET, SQL, Tran-SQL, Windows API, Web Communication, JavaScript, AJAX, CSS, HTML, XML)
May.1 – Aug.30	System Development	Database Development
		User Interface Development
		Network Communication Development
		Application Program Development
Sep.1 - Sep.30	System Test and Evaluation	User Interface Test
		Database Test
		System Functions Test
		System Evaluation
Oct.1 - Nov.30	Thesis Writing and Defense	Thesis Writing and Modification
		Master Thesis Defense

Table 9 Required Development Technology and Schedule

5 System Prototype

5.1 System Interface

Examples of screen shots of software system interfaces developed by the author are in Appendices section.

5.2 System Operation Overview

General Contractor is the system administrator, and is responsible for all system operations and controls. After general contractors sign construction contract with the owner, general contractor will log in this system to save and update project, owner, architect and various project document and activity information in this system. Architects and engineers are responsible for managements of all design documents, and will create, save and update all BIM based design documents in this system. Estimators are responsible for material quantity takeoff and cost estimate results, and could log into the system, choose the relevant project name, import design documents to quantity takeoff and cost estimate platform, make BIM based material quantity takeoff and cost estimate, generate quantity takeoff and cost estimate reports, save and update all relevant reports in this system before the call for material tenders process starts. Material cost estimate reports generated by estimators will provide a more accurate information reference for general contractors to release call for tenders file and evaluate material quotes from suppliers. Site engineers are responsible for the generation, saving, uploading, modification and management of site schedule based material requirement documents in this system.

After the material cost estimate reports and site schedule based material requirement documents are saved to system database, the general contractors will release "Call for Tenders" files according to the cost estimate reports and site schedule documents on this system. All system users including anonymous users could log in this system to view the ongoing and future "Call for Tenders" documents through this website. If one supplier has intention to bid to be a material supplier, he or she will have to contact the general contractor to get an authorized formal user name and password in this system and use this user name and password to submit material quotes through this system during the required time. After all material quotes has been collected, the general contractors will evaluate all material quotes that have been submitted to this system and use the historical supplier performance evaluation information data which have been performed by contractors, estimators, site engineers, purchasers and accountants in the former projects as one reference to make final awarding decisions and sign the material supplying contracts. The important supplier quotes evaluation, awarding and contract signing information will be released on this website on time, and all system users could view such information from this website within their access rights. Document data, information, format and operation requirements should be based on BIM and determined by the general contractor finally.

Supplier performance evaluation provides the valuable historical reference data for contractors to select the best supplier in the future construction project, and it is one of key functions of this system. Contractors, estimators, suppliers, site engineers, purchasers and accountants are all authorized evaluators. General contractors make the final decision about how to evaluate and select potential material suppliers, so choosing and determining weight coefficient of all evaluation criteria and performance indicators is the responsibility and duty of construction contractors. After procurement activities concerning one supplier in one project have finished, it is time for all system evaluators to begin the supplier performance evaluation. Responsible construction contractors first log into this system to determine weight coefficient of each evaluation criterion and performance indicator for all suppliers in one project by choosing a number between 1 and 5 in weight coefficient of each evaluation criterion and performance indicator. Then for all system evaluators, the value of each performance indicator should be selected according to their appraisal of the supplier's performance in the specific project. Each evaluator will choose a number between 1 and 5 in the Choice Value of each indicator according to their appraisal of this supplier's performance in this aspect of this project. After one evaluator finishes the evaluation of one supplier in one project, all evaluated data could be saved to system database. SPIV, ASPIV, SECV, ASECV, TECV and ATECV can be calculated automatically in each project. All evaluated data would be kept as the references for the future decision-making process of material supplier selection. Each evaluator could search project evaluation status, choose an available supplier name and project name to make evaluation, review his or her evaluation history or review past relevant detailed evaluation information. The system will also enable evaluators to select multiple supplier names and one project name to view the comparison and ranking information about evaluation results of the selected different suppliers in the selected project, or select multiple project names and one supplier name to view the comparison and ranking information about evaluation results of the selected supplier in the selected different projects.

5.3 Case Study

This software system could enable cost estimators to enter quantity takeoff and cost estimate platform to generate material quantity takeoff and cost estimate reports based on Autodesk Revit API and RSMeans Unit Price cost data. RSMeans Unit Price cost data are extracted from Unit Price Section of RSMeans Building Construction Cost Data 2008, 66th Annual Edition and stored in Microsoft SQL Server 2005 database of this software system. RSMeans Unit Price cost data could be linked to material quantity takeoff information. All quantity takeoff and cost estimate reports are exported as .CSV file format. For the data complexity and development time restraint, it is difficult to make quantity takeoff or cost estimate on the BIM design model of a building or even a room. Several simple BIM design models that include roof, wall and floor elements are selected to make quantity takeoff case study. A concrete column element and a steel beam element are selected to make cost estimate case study.

5.3.1 Case Study of Material Quantity Takeoff and Cost Estimate

5.3.1.1 Enter Material Quantity Takeoff and Cost Estimate Platform

Before the contractor releases “Call for Tenders” files for a specific future project through this system webpage, cost estimators have authority to select a project name from the available project name list, import relative design documents and enter quantity takeoff and cost estimate platform, which is shown in Figure 12, Figure 13 and Figure 14:

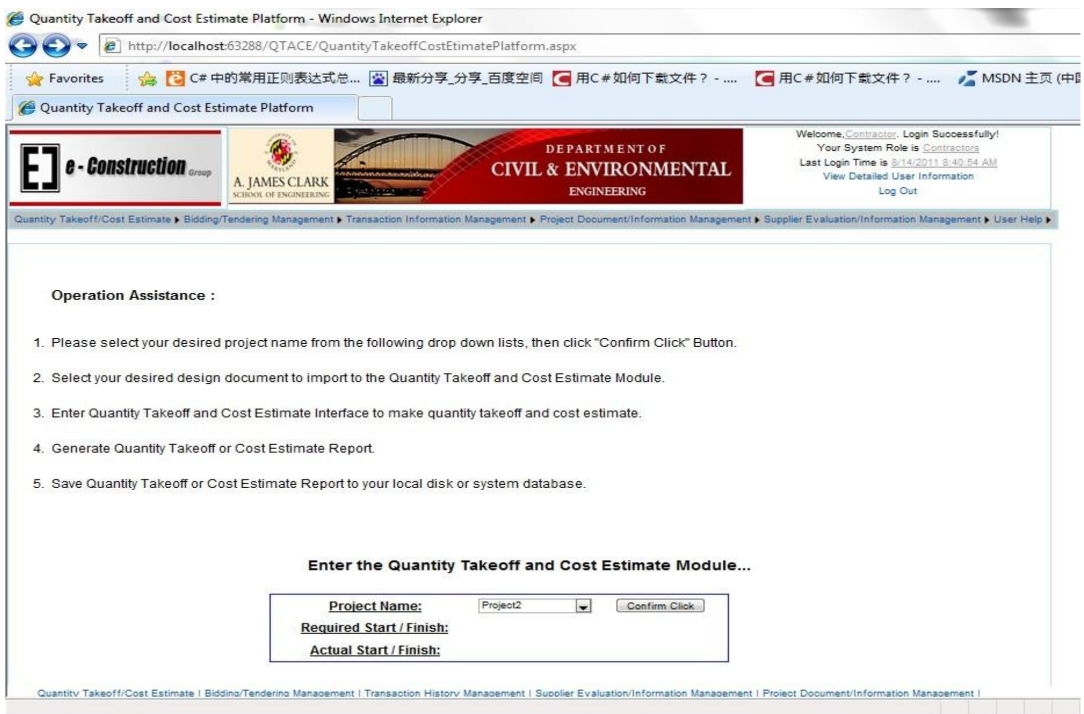


Figure 12 Select a Project Name to Enter Quantity Takeoff and Cost Estimate Platform

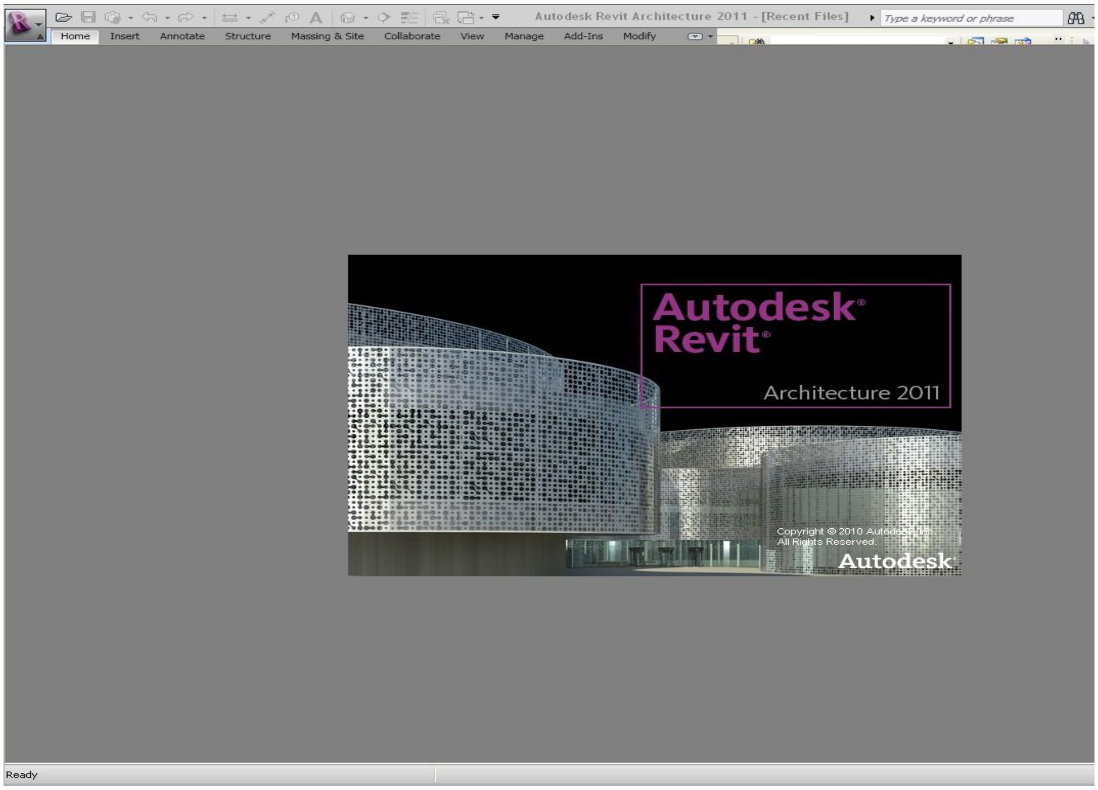


Figure 13 Enter Quantity Takeoff and Cost Estimate Platform

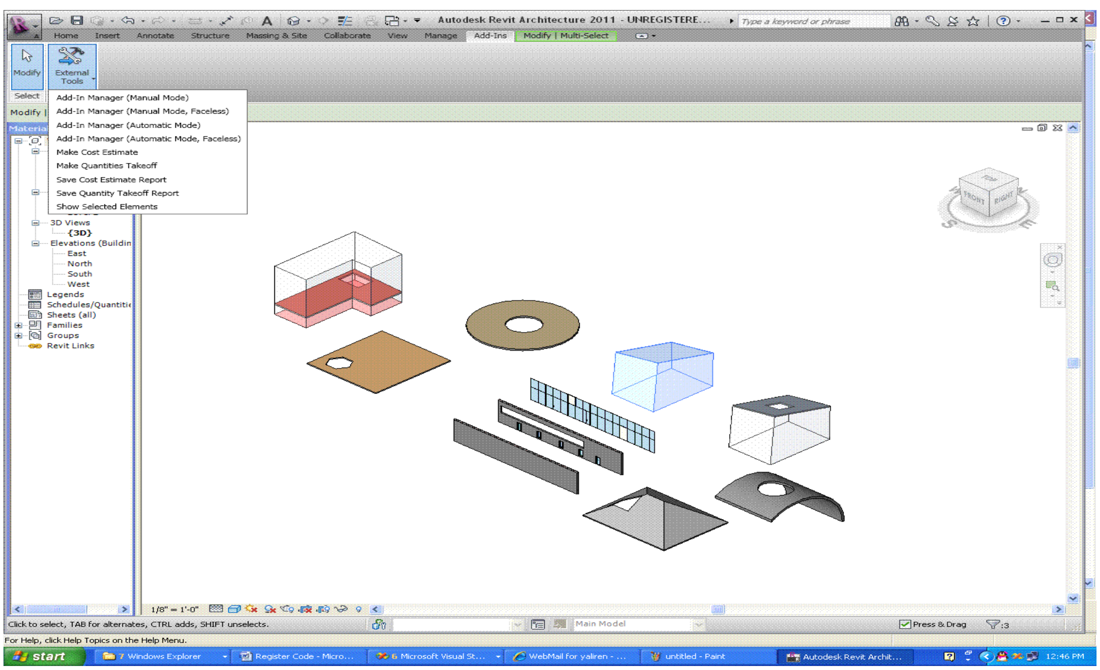


Figure 14 Create, Import and Display BIM Design Document

BIM design documents could be created, imported and displayed to Autodesk Revit platform and Figure 14 shows an example of displaying BIM design document which includes roof elements, wall elements and floor elements. In the External Tools – Add-In Manager at the left upper corner of Figure 14, five functions which include Making Material Cost Estimate, Making Material Quantity Takeoff, Saving Cost Estimate Report, Saving Quantity Takeoff Report and Showing Selected Elements have been developed and added to Autodesk Revit platform.

5.3.1.2 Generate and Save Material Quantity Takeoff Report

Figure 15 shows an example that the authorized cost estimator clicks the submenu of "Make Quantity Takeoff" in the Add-In Manager. After the cost estimators clicks the submenu of "Make Quantity Takeoff" in the Add-In Manager, this system will calculate the quantity information of all elements in the active design document and display detailed quantity information in Figure 16 and Figure 17. The quantity takeoff report includes general and detailed information which comprises Element Type, Element Id, Element Name, Element Material Composition, Gross Volume, Net Volume, Gross Area and Net Area information of all BIM elements in the design file.

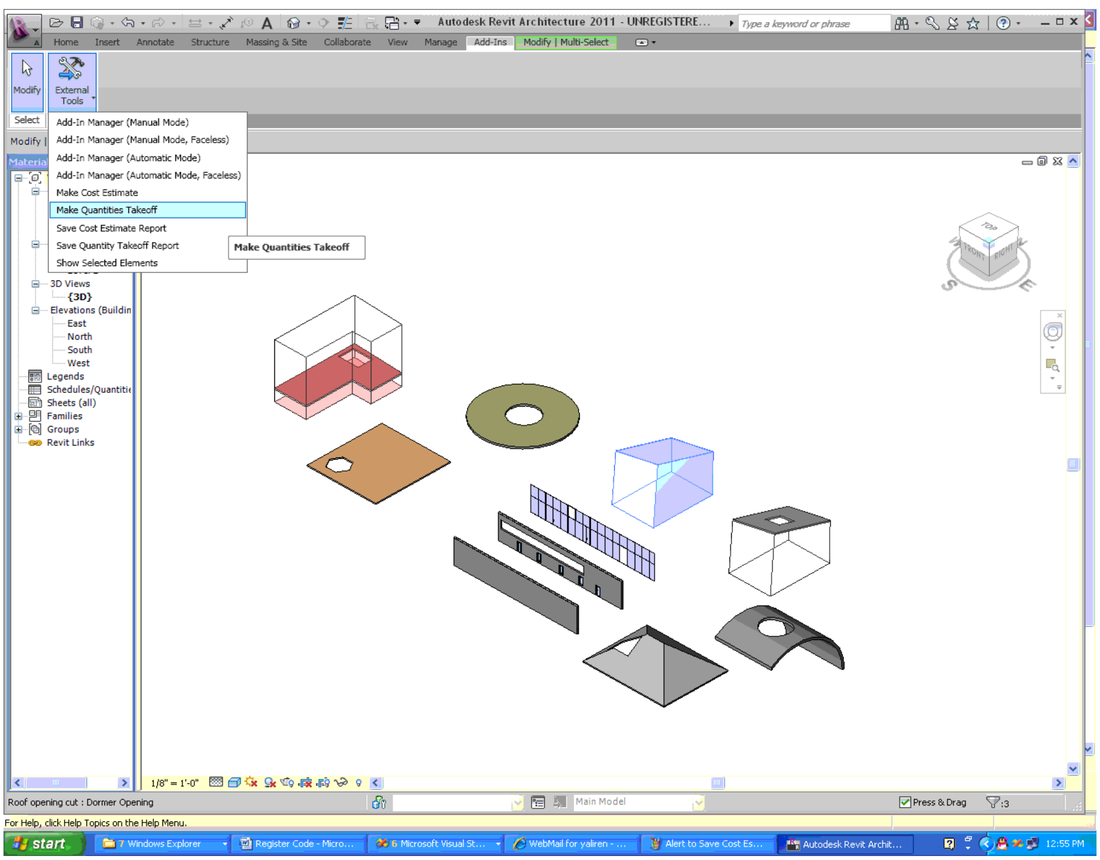
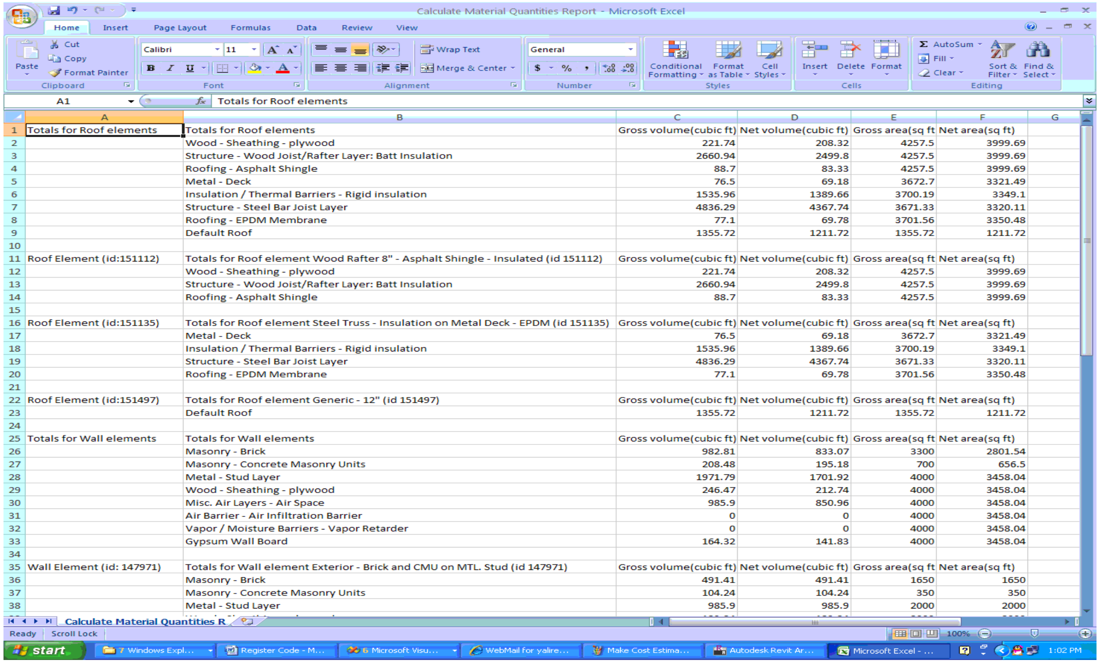
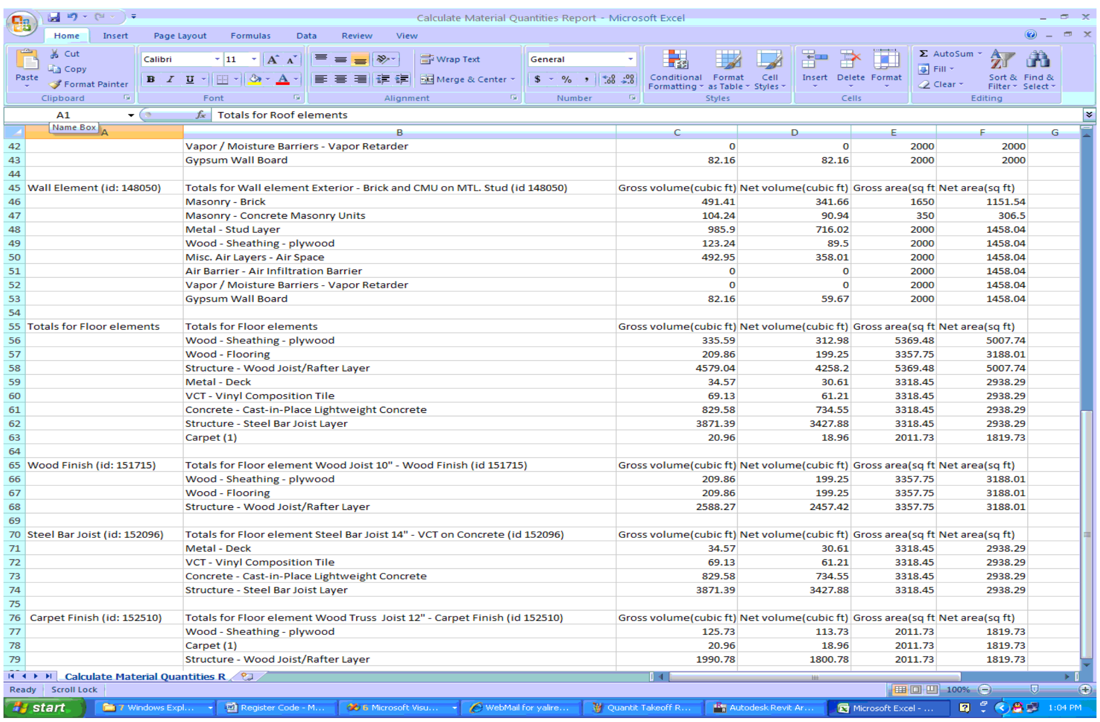


Figure 15 Operation to Make Material Quantity Takeoff



	A	B	C	D	E	F
1	Totals for Roof elements	Totals for Roof elements	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
2		Wood - Sheathing - plywood	221.74	208.32	4257.5	3999.69
3		Structure - Wood Joist/Rafter Layer: Batt Insulation	2660.94	2499.8	4257.5	3999.69
4		Roofing - Asphalt Shingle	88.7	83.33	4257.5	3999.69
5		Metal - Deck	76.5	69.18	3672.7	3321.49
6		Insulation / Thermal Barriers - Rigid insulation	1535.96	1389.66	3700.19	3349.1
7		Structure - Steel Bar Joist Layer	4836.29	4367.74	3671.33	3320.11
8		Roofing - EPDM Membrane	77.1	69.78	3701.56	3350.48
9		Default Roof	1355.72	1211.72	1355.72	1211.72
10						
11	Roof Element (id:151112)	Totals for Roof element Wood Rafter 8" - Asphalt Shingle - Insulated (id 151112)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
12		Wood - Sheathing - plywood	221.74	208.32	4257.5	3999.69
13		Structure - Wood Joist/Rafter Layer: Batt Insulation	2660.94	2499.8	4257.5	3999.69
14		Roofing - Asphalt Shingle	88.7	83.33	4257.5	3999.69
15						
16	Roof Element (id:151135)	Totals for Roof element Steel Truss - Insulation on Metal Deck - EPDM (id 151135)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
17		Metal - Deck	76.5	69.18	3672.7	3321.49
18		Insulation / Thermal Barriers - Rigid insulation	1535.96	1389.66	3700.19	3349.1
19		Structure - Steel Bar Joist Layer	4836.29	4367.74	3671.33	3320.11
20		Roofing - EPDM Membrane	77.1	69.78	3701.56	3350.48
21						
22	Roof Element (id:151497)	Totals for Roof element Generic - 12" (id 151497)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
23		Default Roof	1355.72	1211.72	1355.72	1211.72
24						
25	Totals for Wall elements	Totals for Wall elements	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
26		Masonry - Brick	982.81	833.07	3300	2801.54
27		Masonry - Concrete Masonry Units	208.48	195.18	700	656.5
28		Metal - Stud Layer	1971.79	1701.92	4000	3458.04
29		Wood - Sheathing - plywood	246.47	212.74	4000	3458.04
30		Misc. Air Layers - Air Space	985.9	850.96	4000	3458.04
31		Air Barrier - Air Infiltration Barrier	0	0	4000	3458.04
32		Vapor / Moisture Barriers - Vapor Retarder	0	0	4000	3458.04
33		Gypsum Wall Board	164.32	141.83	4000	3458.04
34						
35	Wall Element (id: 147971)	Totals for Wall element Exterior - Brick and CMU on MTL. Stud (id 147971)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
36		Masonry - Brick	491.41	491.41	1650	1650
37		Masonry - Concrete Masonry Units	104.24	104.24	350	350
38		Metal - Stud Layer	985.9	985.9	2000	2000

Figure 16 View Quantity Takeoff Report (Part 1)



	A	B	C	D	E	F
42		Vapor / Moisture Barriers - Vapor Retarder	0	0	2000	2000
43		Gypsum Wall Board	82.16	82.16	2000	2000
44						
45	Wall Element (id: 148050)	Totals for Wall element Exterior - Brick and CMU on MTL. Stud (id 148050)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
46		Masonry - Brick	491.41	341.66	1650	1151.54
47		Masonry - Concrete Masonry Units	104.24	90.94	350	306.5
48		Metal - Stud Layer	985.9	716.02	2000	1458.04
49		Wood - Sheathing - plywood	123.24	89.5	2000	1458.04
50		Misc. Air Layers - Air Space	492.95	358.01	2000	1458.04
51		Air Barrier - Air Infiltration Barrier	0	0	2000	1458.04
52		Vapor / Moisture Barriers - Vapor Retarder	0	0	2000	1458.04
53		Gypsum Wall Board	82.16	59.67	2000	1458.04
54						
55	Totals for Floor elements	Totals for Floor elements	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
56		Wood - Sheathing - plywood	335.59	312.98	5369.48	5007.74
57		Wood - Flooring	209.86	199.25	3357.75	3188.01
58		Structure - Wood Joist/Rafter Layer	4579.04	4258.2	5369.48	5007.74
59		Metal - Deck	34.57	30.61	3318.45	2938.29
60		VCT - Vinyl Composition Tile	69.13	61.21	3318.45	2938.29
61		Concrete - Cast-in-Place Lightweight Concrete	829.58	734.55	3318.45	2938.29
62		Structure - Steel Bar Joist Layer	3871.39	3427.88	3318.45	2938.29
63		Carpet (1)	20.96	18.96	2011.73	1819.73
64						
65	Wood Finish (id: 151715)	Totals for Floor element Wood Joist 10" - Wood Finish (id 151715)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
66		Wood - Sheathing - plywood	209.86	199.25	3357.75	3188.01
67		Wood - Flooring	209.86	199.25	3357.75	3188.01
68		Structure - Wood Joist/Rafter Layer	2588.27	2457.42	3357.75	3188.01
69						
70	Steel Bar Joist (id: 152096)	Totals for Floor element Steel Bar Joist 14" - VCT on Concrete (id 152096)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
71		Metal - Deck	34.57	30.61	3318.45	2938.29
72		VCT - Vinyl Composition Tile	69.13	61.21	3318.45	2938.29
73		Concrete - Cast-in-Place Lightweight Concrete	829.58	734.55	3318.45	2938.29
74		Structure - Steel Bar Joist Layer	3871.39	3427.88	3318.45	2938.29
75						
76	Carpet Finish (id: 152510)	Totals for Floor element Wood Truss Joist 12" - Carpet Finish (id 152510)	Gross volume(cubic ft)	Net volume(cubic ft)	Gross area(sq ft	Net area(sq ft)
77		Wood - Sheathing - plywood	125.73	113.73	2011.73	1819.73
78		Carpet (1)	20.96	18.96	2011.73	1819.73
79		Structure - Wood Joist/Rafter Layer	1990.78	1800.78	2011.73	1819.73

Figure 17 View Quantity Takeoff Report (Part 2)

After the quantity takeoff report is generated, the authorized cost estimator is able to determine if the present quantity takeoff report should be saved to system database. If the cost estimator determines to save present quantity takeoff report to system database, they can click the submenu of "Save Quantity Takeoff Report". Figure 18 shows the instance that the cost estimator clicks the submenu of "Save Quantity Takeoff Report". Figure 19 shows the system message that quantity takeoff report has been successfully saved to system database.

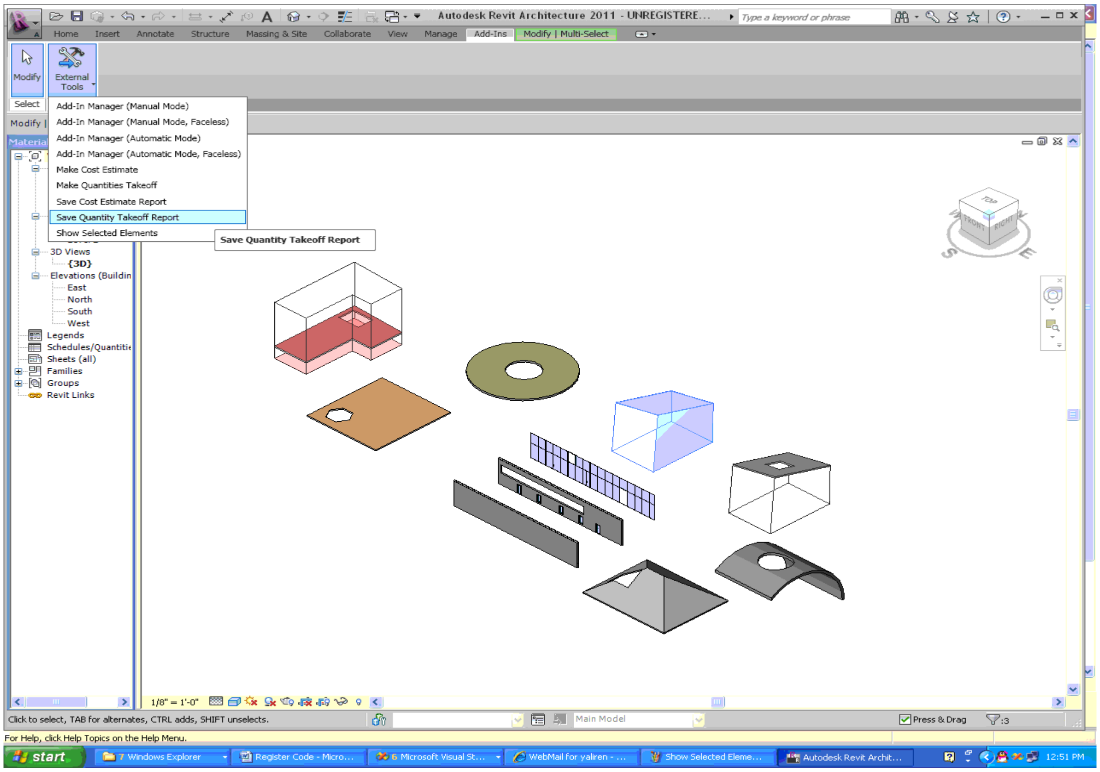


Figure 18 Operation to Save Quantity Takeoff Report

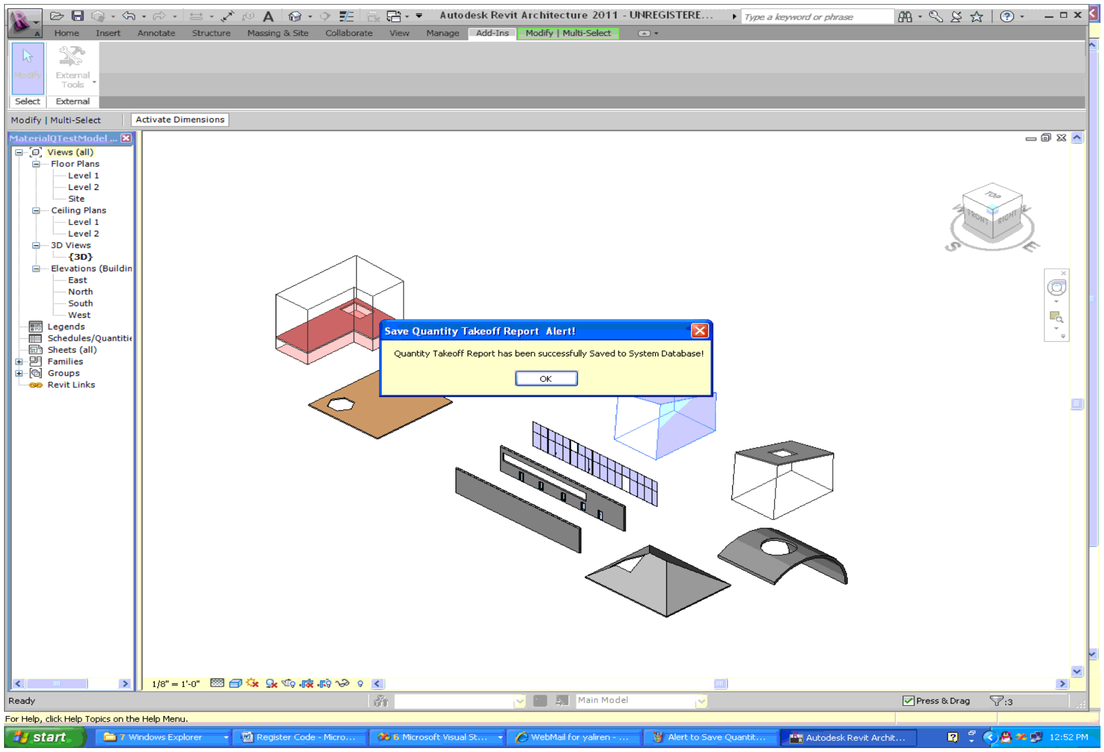


Figure 19 Message of Saving Quantity Takeoff Report to Database

5.3.1.3 Generate and Save Material Cost Estimate Report

One round concrete column element and one steel beam element are selected as examples to make cost estimate operation. The concrete column is round, tied, 12'' diameter and has average reinforcing. The calculation unit for this round column is Cubic Foot (C.F.), and this column has 54.6 calculation units. The unit price data is $485 per Cubic Yard (C.Y.), and the conversion from C.Y. to C.F. is 1 C.Y. = 27 C.F.. The material cost of this concrete column is calculated as $ 485*54.6/27= 980.78. The steel beam is W12*26. The calculation unit for this steel beam is Linear Foot (L.F.), and this steel beam has 10.2 calculation units. The unit price data of per calculation unit is $31.5/L.F.. The material cost of this steel beam is calculated as $ 10.2*31.5=321.30.

Figure 20 shows an example that the cost estimator clicks the submenu of "Make Cost Estimate" in the Add-In Manager. After the cost estimator clicks the submenu of "Make Cost Estimate" in the Add-In Manager, this system will calculate the cost estimate information for all elements in the design document and display detailed cost estimate information in Figure 21. The cost estimate report includes the information of Element Type, Element Id, Element Name, Element Material Composition, Calculation Unit, Unit Price, Element Cost and Total Cost.

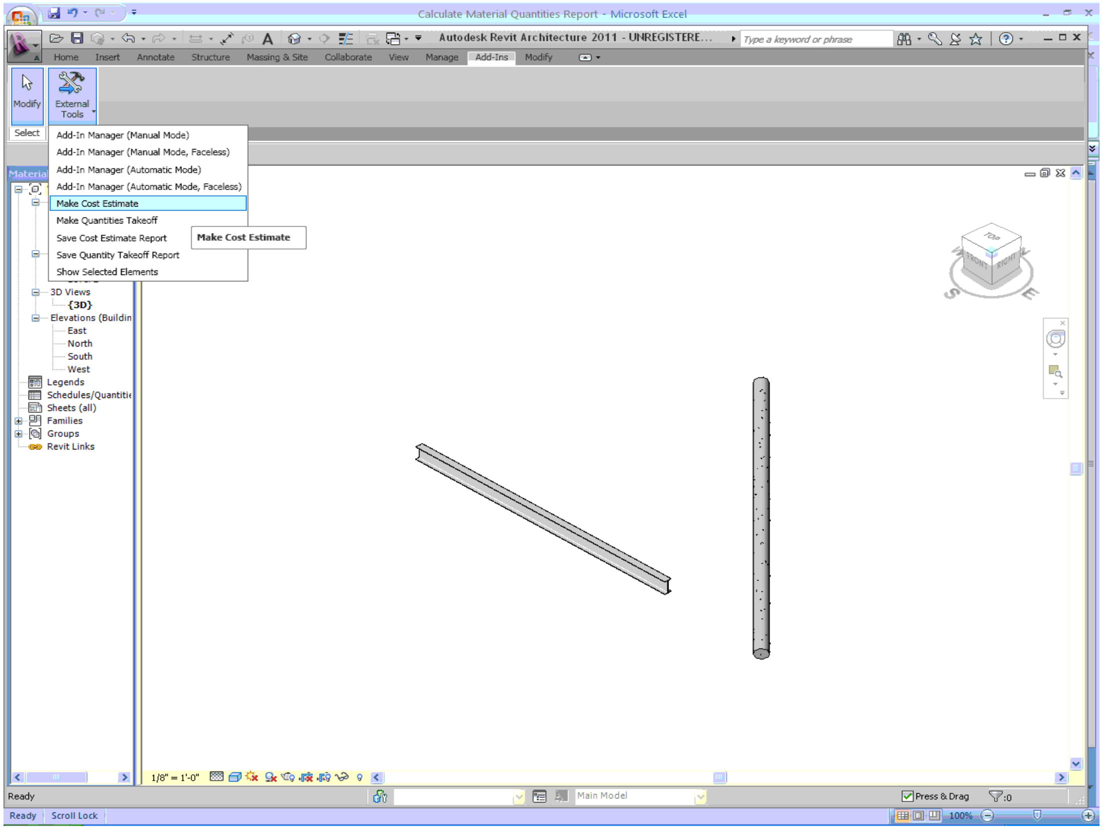
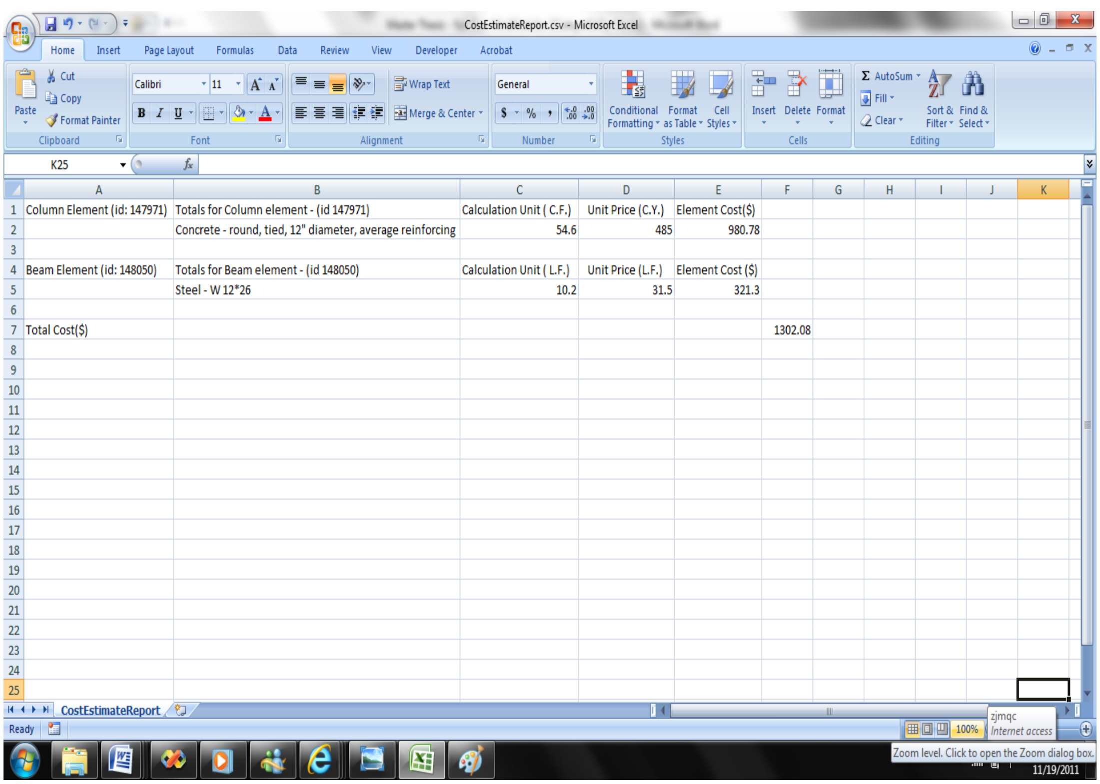


Figure 20 Operation to Make Cost Estimate



	A	B	C	D	E	F
1	Column Element (id: 147971)	Totals for Column element - (id 147971)	Calculation Unit (C.F.)	Unit Price (C.Y.)	Element Cost($)	
2		Concrete - round, tied, 12" diameter, average reinforcing	54.6	485	980.78	
3						
4	Beam Element (id: 148050)	Totals for Beam element - (id 148050)	Calculation Unit (L.F.)	Unit Price (L.F.)	Element Cost ($)	
5		Steel - W 12*26	10.2	31.5	321.3	
6						
7	Total Cost($)					1302.08

Figure 21 View Cost Estimate Report

Figure 22 shows an example that the cost estimator could click the submenu of "Save Cost Estimate Report". Figure 23 shows a system message that the cost estimate report has been saved to system database successfully.

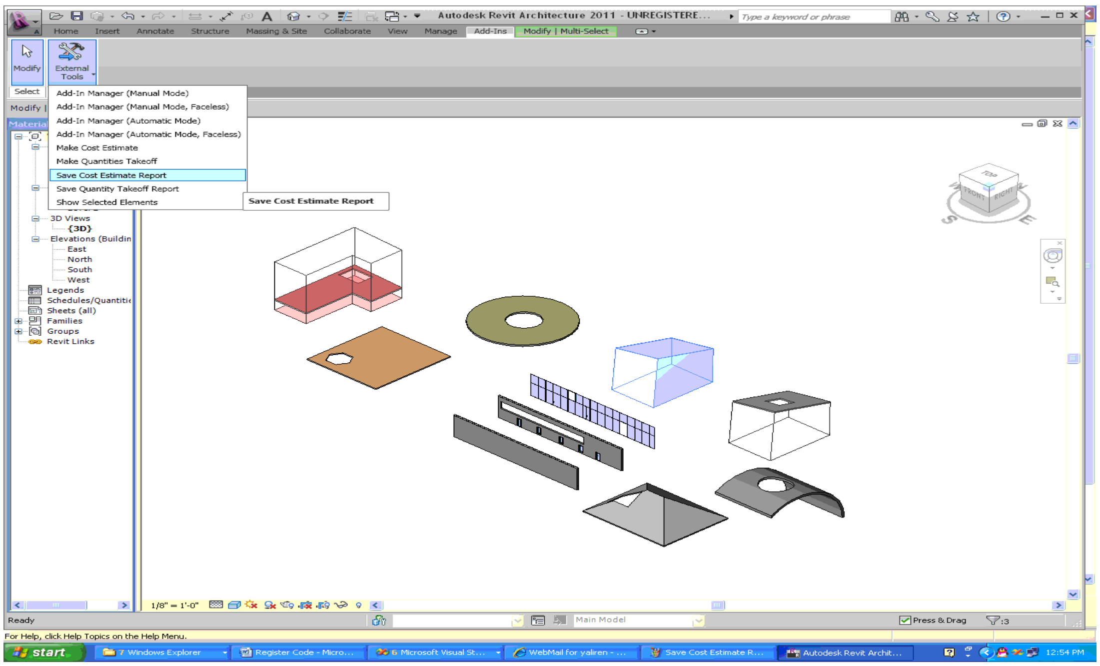


Figure 22 Operation to Save Cost Estimate Report

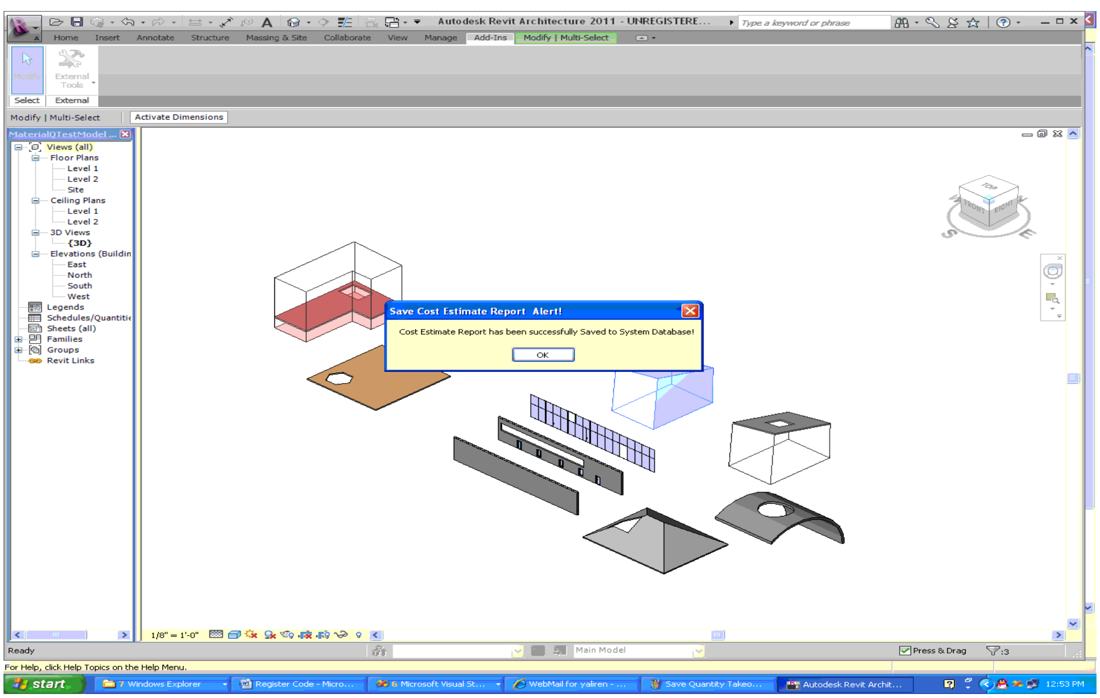


Figure 23 Message about Saving Cost Estimate Report to Database

5.3.1.4 Show Selected Element Information

This system allows the authorized cost estimators to select several or all BIM design elements and view the Type, ID and Name information of selected elements. Figure 24 shows an example that the cost estimator could click the submenu of “Show Selected Elements” and select all elements in the design document. Figure 25 shows the system interface that displays Type, ID and Name information of all elements in the design document.

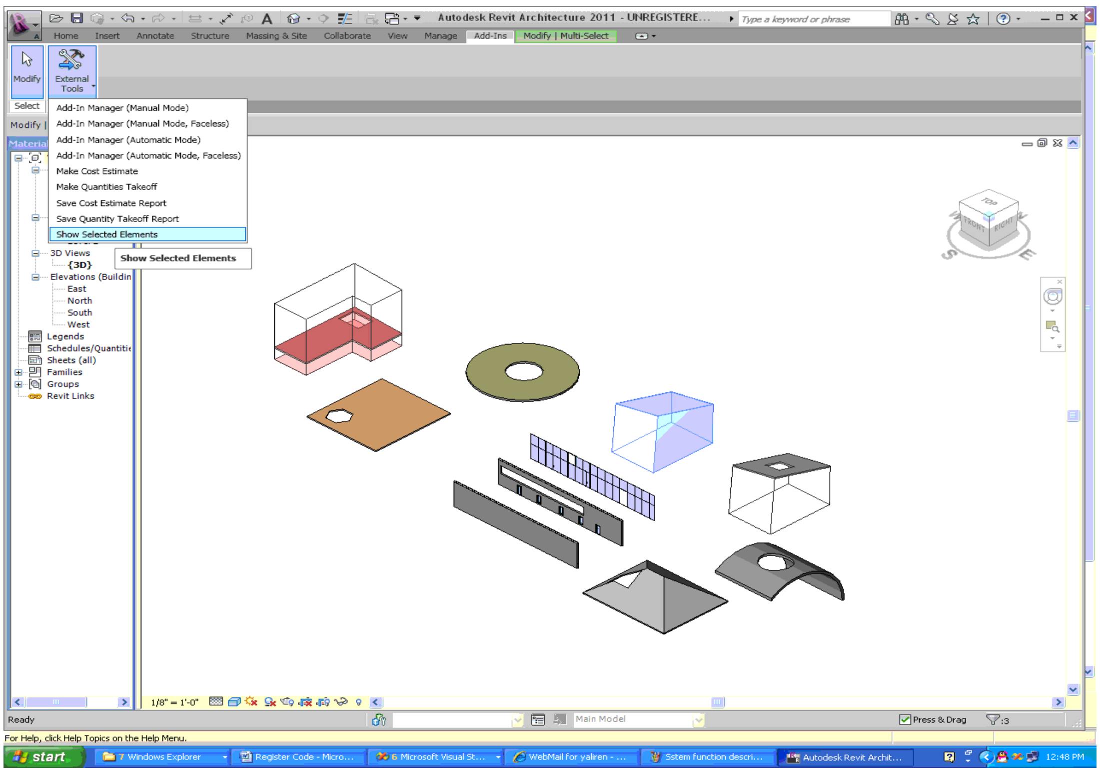


Figure 24 Operation to Show Selected Elements

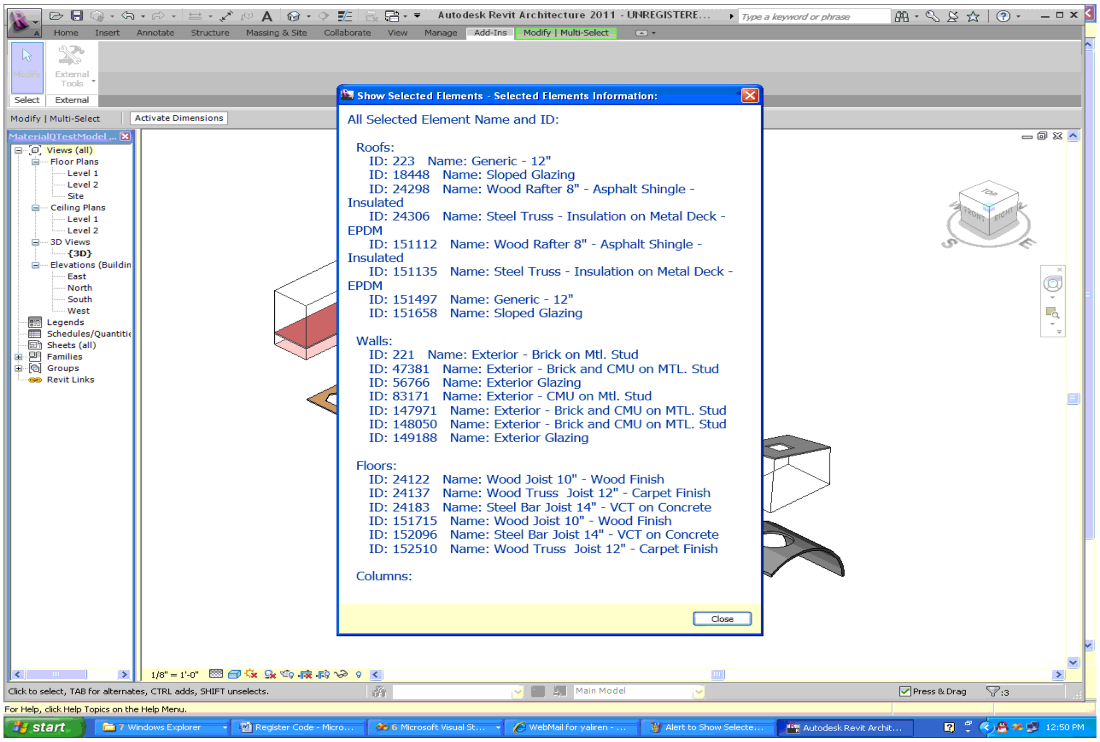


Figure 25 Show Type, ID and Name Information of All Elements

5.3.1.5 Advantage and Usage of Quantity Takeoff and Cost Estimate Report

Quantity takeoff and cost estimate reports generated from this platform will be more accurate, and cost less time and labor, compared with the traditional quantity takeoff and cost estimate methods. It will be more convenient for cost estimators to discover design, quantity takeoff and cost estimate errors and make modifications based on BIM. These reports could be as the reference for cost estimators or contractors to do further data processing for the future bidding, tendering and awarding work, and provide more accurate material quantity and cost standards to evaluate future material quotes and select potential material suppliers.

5.3.2 Case Study of Supplier Performance Evaluation

5.3.2.1 Evaluate One Supplier's Performance in One Project

After the procurement processes concerning one material supplier in one project finish, the relevant project name and supplier name will be shown on the available project name list and supplier name list in Figure 26. The general contractor will log into supplier performance evaluation function as the system administrator to determine the weight coefficient value of all evaluation criteria and performance indicators in one project from a number between 1 and 5 according to the understanding and ranking the importance of each evaluation criterion and performance indicator. The interface of inputting weight coefficient value of all evaluation criteria and performance indicators for "Project12" is as an example and displayed in Figure 26.

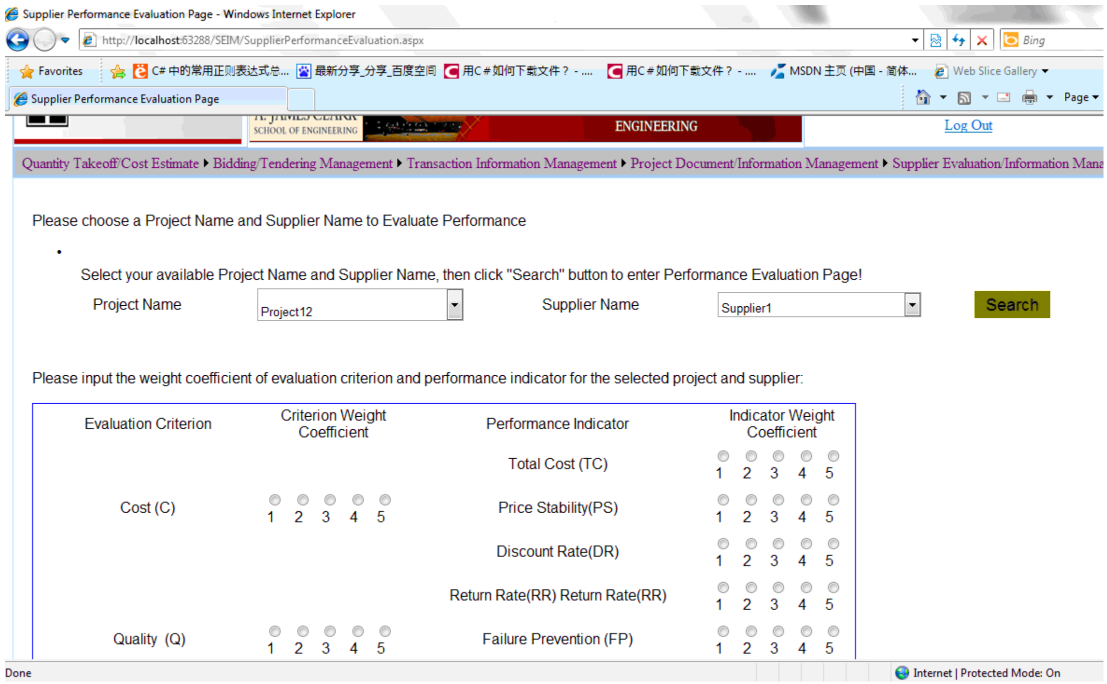


Figure 26 Input Weight Coefficient Value of Evaluation Criteria and Performance Indicators of One Project

If an authorized system evaluator has evaluated the selected supplier's performance in the selected project before, the system interface will show an alert dialogue to notify that the evaluator has evaluated the selected supplier's performance in the selected project, and to warn that this evaluator should choose another combination of project name and supplier name because this system does not allow the same evaluator to evaluate the same supplier's performance in the same project more than once. Figure 27 shows an example that the system displays the warning information which does not allow the performance evaluation process to begin when the authorized evaluator selects the performance evaluation of "Supplier1" in "Project10" because this authorized evaluator has finished it before.

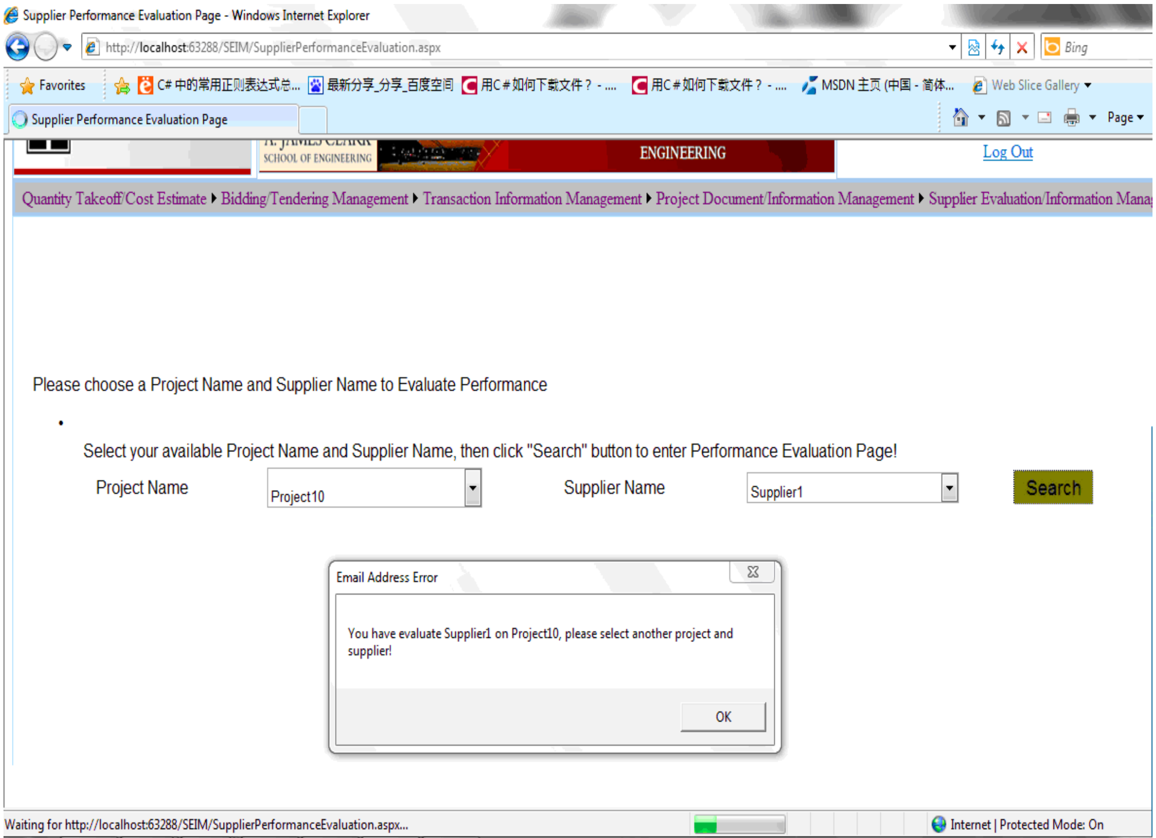


Figure 27 Choose a Supplier Name and Project Name to Evaluate

If the selected supplier's performance in the selected project has not been evaluated by the authorized performance evaluator before, the system interface will show one message to display weight coefficient value of all evaluation criteria and performance indicators about this project and allow this evaluator to evaluate the performance of this supplier in this project. Figure 28 shows a message to allow the system evaluator to make performance evaluation about "Supplier3" in "Project7".

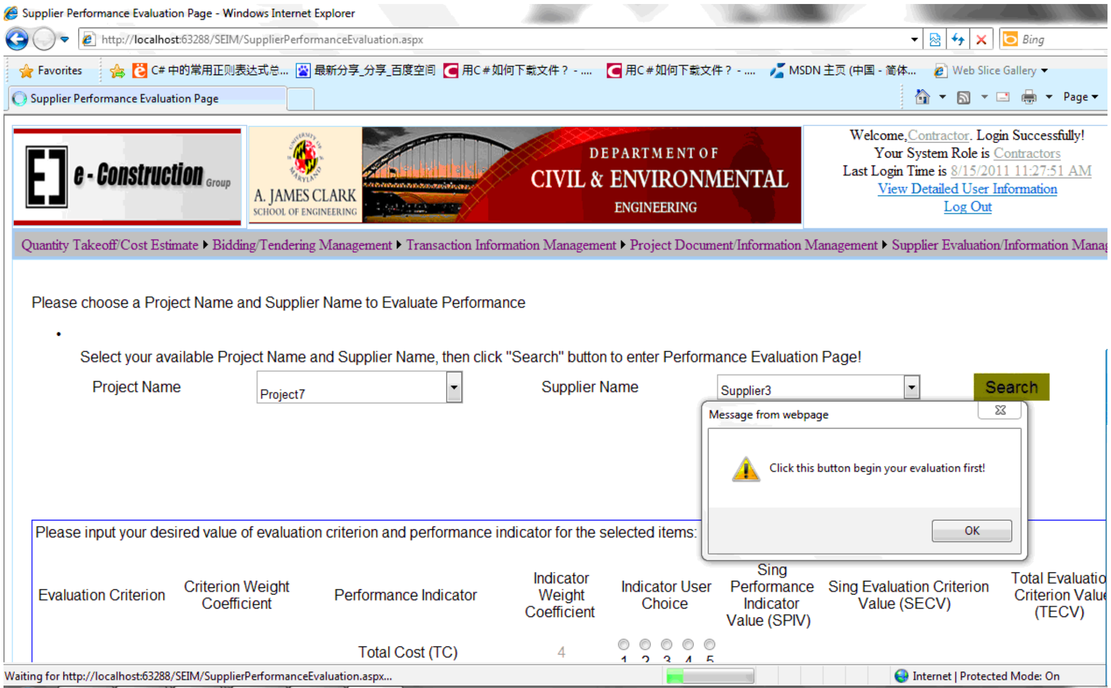


Figure 28 Click “OK” Button to Begin Supplier Performance Evaluation

Figure 29 shows an instance that that the authorized supplier performance evaluator begins the supplier performance evaluation about “Supplier3” in “Project7”. Figure 30 shows the dialog message to inquire if the authorized supplier performance evaluator would like to save the performance evaluation data to system database.

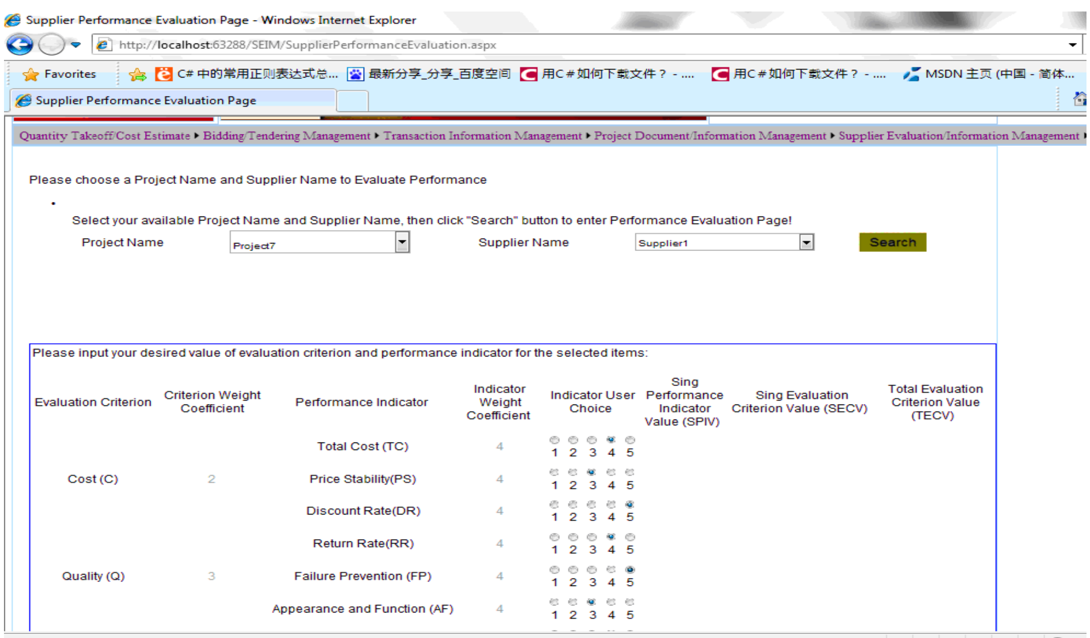


Figure 29 Select Choice Value of One Project and One Supplier for Performance Evaluation

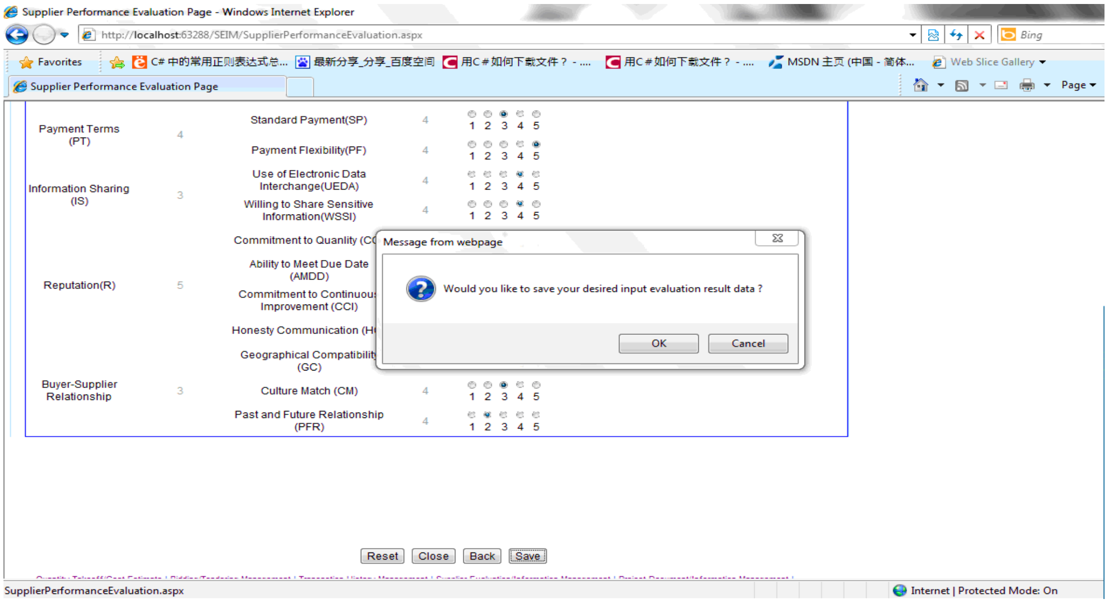


Figure 30 Inquire if the Evaluator Wish to Save Performance Evaluation Data

If the supplier performance evaluator chooses “Ok” in Figure 30, then this system will automatically save the performance evaluation data of this supplier in this project performed by this evaluator. Figure 31 shows the dialog message to inquire if the supplier performance evaluator would like to continue making supplier performance evaluation of different combination of project name and supplier name if the evaluation on the selected supplier’s performance in the selected project finishes.

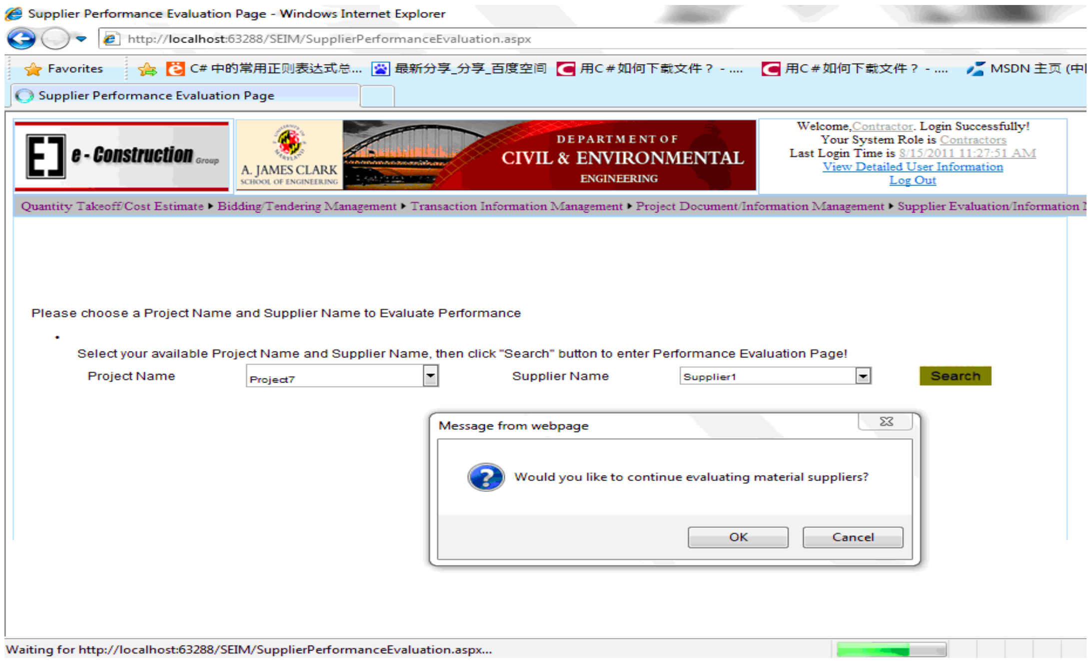


Figure 31 Query about Whether to Continue next Supplier Performance Evaluation

If the supplier performance evaluator chooses "OK" in Figure 31, then the system will stay on the same supplier performance evaluation webpage to allow the evaluator to choose the different combination of supplier name and project name to continue another supplier performance evaluation process.

Table 10 shows one performance evaluator's evaluation information and all performance evaluator's average evaluation information about "Supplier1" in "Project2" as an example. EC represents Evaluation Criterion, ECV represents Evaluation Criterion Value in one project, PI represents Performance Indicator, PIV represents Performance Indicator Value in one project, CV represents Choice Value of a performance indicator's input performed by one evaluator, ACV represents Average Choice Value of a performance indicator's input by all evaluators, SPIV represents Single Performance Indicator Value, ASPIV represents Average Single Performance Indicator Value, SECV represents Single Evaluation Criterion Value, ASECV represents Average Single Evaluation Criterion Value, TECV represents Total Evaluation Criterion Value and ATECV represents Average Total Evaluation Criterion Value. Other meaning of the abbreviated letters in Table 10 could make references to Table 6 and Table 7 in Section 3.3. The calculation method of the data in Table 10 could also make references to the method list Function 1 to Function 7 in Section 3.3.

EC (ECV)	**PI (PIV)**	**CV(ACV)**	**SPIV (ASPIV)**	**SECV (ASECV)**	**TECV (ATECV)**
C (3)	TC (5)	3(3)	15(15)	40(40)	1077
	PS (3)	3(3)	9(9)		

	DR (4)	4(4)	16(16)		(1077)
Q (4)	RR (4)	4(4)	16(16)	46(46)	
	FP (4)	5(5)	20(20)		
	AF (2)	5(5)	10(10)		
D (5)	LT (1)	4(4)	4(4)	35(35)	
	OTD (4)	4(4)	16(16)		
	DF (5)	3(3)	15(15)		
S(2)	SS (5)	4(4)	20(20)	32(32)	
	TAS (3)	2(2)	6(6)		
	CC (3)	2(2)	6(6)		
AS(2)	C (4)	5(5)	20(20)	45(45)	
	R (4)	5(5)	20(20)		
	F (1)	5(5)	5(5)		
OA(5)	TA (2)	5(5)	10(10)	49(49)	
	CBS (3)	4(4)	12(12)		
	MA (4)	3(3)	12(12)		
	PA (5)	3(3)	15(15)		
PT (1)	SP (4)	4(4)	16(16)	26(26)	
	PF (2)	5(5)	10(10)		
IS(1)	UEDA (1)	5(5)	5(5)	9(9)	
	WSSI (1)	4(4)	4(4)		
R(1)	CQ (3)	3(3)	9(9)	44(44)	
	AMDD (3)	3(3)	9(9)		
	CCI (4)	4(4)	16(16)		
	HC (2)	5(5)	10(10)		
BSR(3)	GC (2)	5(5)	10(10)	40(40)	
	CM (5)	4(4)	20(20)		
	PFR (5)	2(2)	10(10)		

Table 10 Example of Performance Evaluator's Evaluation Information

Take the calculation process of CV (ACV), SPIV (ASPIV) and SECV (ASECV) in the first evaluation criterion (Cost, C) section, and TECV (ATECV) in Table 10 as an example. From the Table 10, one evaluator that has the user role "Contractors" has determined Evaluation Criterion Value (ECV) in the Cost(C) of Evaluation Criterion (EC) as 3, and the Performance Indicator Value (PIV) of Total Cost (TC) as 5, and the PIV of Price Stability (PS) as 3 and the PIV of Discount Rate (DR) as 4 in "Project2". Another authorized evaluator has input the Choice Value (CV) of TC as 3, the CV of PS as 3 and the CV of DR as 4 in the performance evaluation of "Supplier1" in "Project2". Based on Function 1 in Section 3.3, the SPIV of TC could be calculated as 3*5 = 15, the SPIV of PS could be calculated as 3*3 = 9, and the SPIV of DR could be calculated as 4*4 = 16. The three numbers 15, 9 and 13 are listed respectively in the intersect space of Row "TC" and Column "SPIV", Row "PS" and Column "SPIV" and Row "DR" and Column "SPIV". From Function 2 in

Section 3.3, SECV in Cost (C) section of evaluation criterion could be calculated as 15 + 9 + 16 = 39, and the number 39 is listed in the in intersect space of Row “C” and Column “SECV”. Calculation of other values of SPIV and SECV columns is the same as the above process. From Function 3 in Section 3.3, TECV could be calculated as 40*3 + 46*4 + 35*5 + 32*2 + 45 *2 + 49*5 + 26*1 + 9*1 + 44*1 + 40*3 = 120 + 184 +175 + 64 + 90 + 245 + 26 + 9 + 44 + 120 = 1077. The number 1077 is listed in the column of TECV in Table 10.

In Table 10, only one performance evaluator finishes the performance evaluation of “Supplier1” in “Project2”, so N equals 1, ACV equals CV, ASPIV equals SPIV, ASECV equals SECV and ATECV equals TECV. Normally when N>1, ACV does not equal CV, ASPIV does not equal SPIV, ASECV does not equal SECV and ATECV does not equal TECV.

In this system, one authorized supplier performance evaluator normally has access rights to view his or her detailed evaluation information that has been saved to the system database about each supplier in each project. One evaluator also has access rights to view average evaluation information of one supplier in one project that has been performed by all evaluators and saved to the system database on the condition that this evaluator has finished the performance evaluation of this supplier in this project and saved the evaluation record to the system database. For example, if one authorized evaluator has the user role as “Estimators” and has finished the performance evaluation of “Supplier1” in “Project2” and the data in Table 10 is evaluated by this evaluator, then this evaluator has access rights to view all the data in Table 10. One authorized supplier performance evaluator normally has no access rights to view any finished and saved detailed evaluation record information of any supplier in any relevant project performed by any other authorized performance evaluator. If an authorized evaluator has the user role as Contractors, he or she has also the access rights to view all finished and saved detailed evaluation record information of all suppliers in all relevant projects performed by all authorized performance evaluators.

5.3.2.2 Compare Multiple Suppliers’ Performance in One Project

If the supplier performance evaluation of several suppliers in one project has been completed, then this system allows authorized performance evaluators to select one project name and several supplier names to compare and rank these suppliers’ performance evaluation results in this project. Figure 32 shows that the supplier performance evaluator selects “Supplier1”,”Supplier2” and “Supplier3” and “Project7” to view and compare the selected suppliers’ performance evaluation results in the selected project.

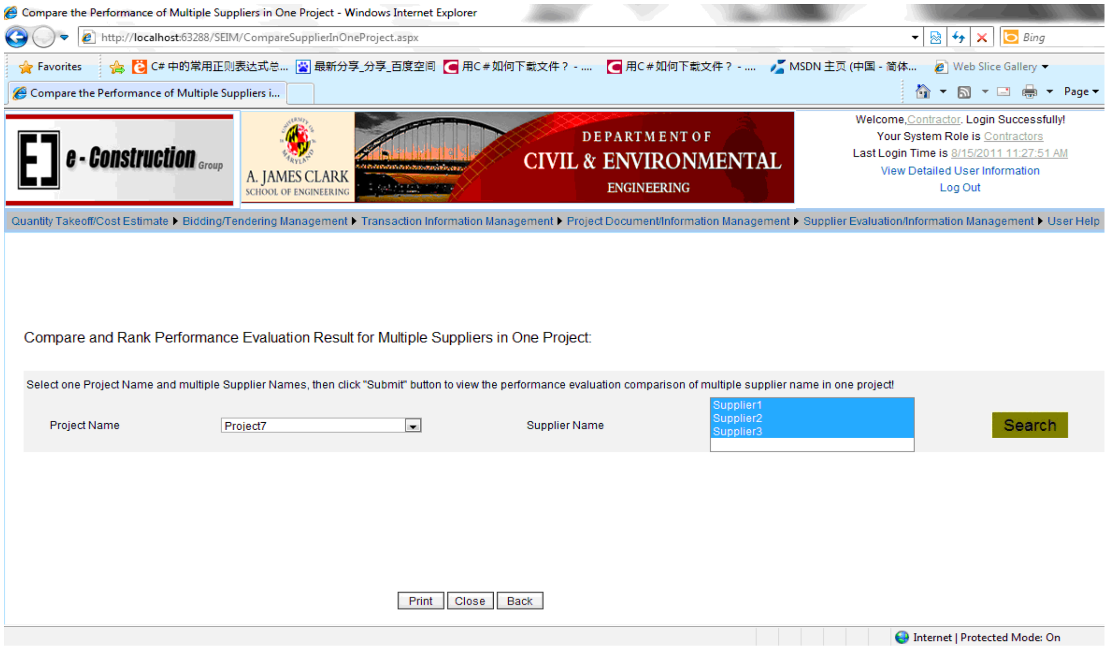


Figure 32 Choose Multiple Suppliers in One Project to Compare Evaluation Result

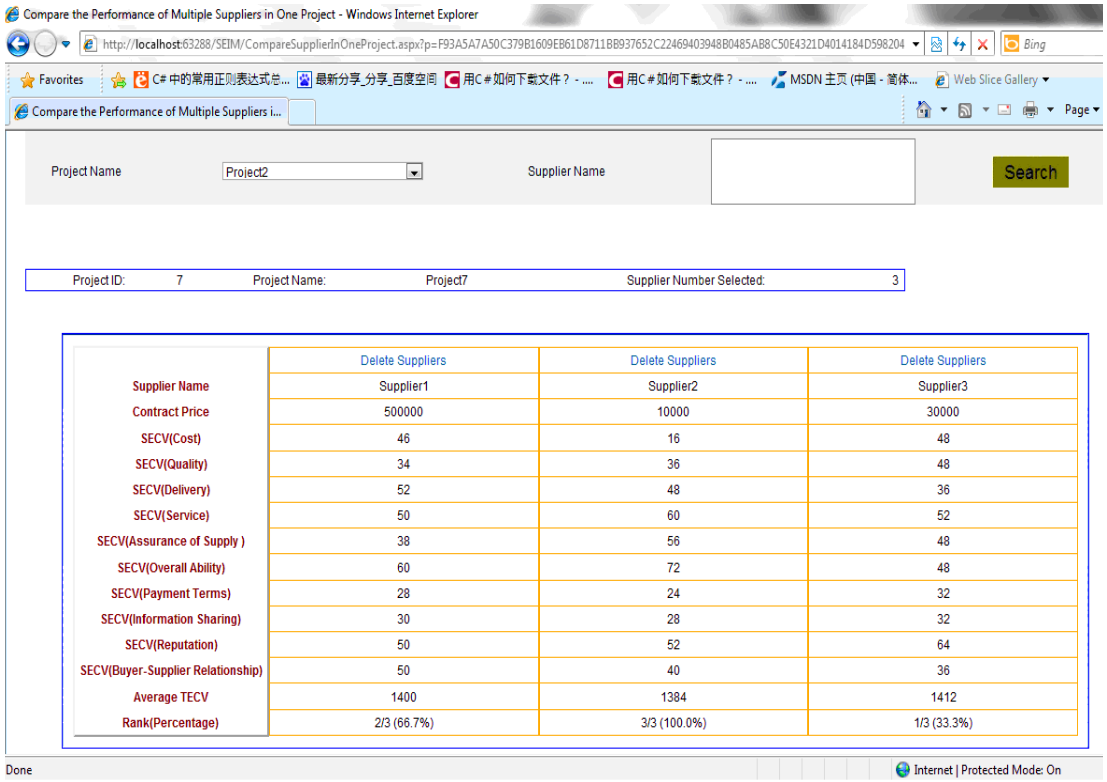
Table 11 shows the average evaluation information including ECV, PIV, ACV, ASECV and ATECV about the selected suppliers in "Project7" performed by all performance evaluators. All the data in ECV, PIV and ACV columns are inputted into the system by the author randomly as the example to introduce the system function. ASECV and ATECV are calculated by the software system based on the randomly inputted ECV, PIV and ACV data. Other meanings of the abbreviated letters in Table 11 could make reference to Table 6 and Table 7 in Section 3.3. The calculation method of the data in Table 11 could also make reference to the method list Function 1 to Function 7 in Section 3.3.

Project Name: Project7		**Supplier Name:** Supplier1, Supplier2, Supplier3					
EC (ECV)	**PI (PIV)**	**Supplier1**		**Supplier2**		**Supplier3**	
		ACV	**ASECV**	**ACV**	**ASECV**	**ACV**	**ASECV**
C (2)	TC (4)	4	46	1	16	4	48
	PS (4)	4		1		3	
	DR (4)	3.5		2		5	
Q (3)	RR (4)	2.5	34	3	36	4	48
	FP (4)	2.5		3		5	
	AF (4)	3.5		3		3	
D (5)	LT (4)	3.5	52	4	48	2	36
	OTD (4)	5		4		3	
	DF (4)	4.5		4		4	
S(1)	SS (4)	5	50	5	60	4	52
	TAS (4)	4		5		5	

	CC (4)	3.5		5		4	
AS(3)	C (4)	2	38	5	56	3	48
	R (4)	2.5		5		4	
	F (4)	5		4		5	
OA(3)	TA (4)	2	60	4	72	5	48
	CBS (4)	4.5		4		4	
	MA (4)	5		5		2	
	PA (4)	3.5		5		1	
PT (4)	SP (4)	3	28	3	24	3	32
	PF (4)	4		3		5	
IS(3)	UEDA (4)	3	30	3	28	4	32
	WSSI (4)	4.5		4		4	
R(5)	CQ (4)	4	50	4	52	3	64
	AMDD (4)	2		5		4	
	CCI (4)	4		2		4	
	HC (4)	2.5		2		5	
BSR(3)	GC (4)	4.5	50	3	40	4	36
	CM (4)	4		5		3	
	PFR (4)	4		2		2	
ATECV		1400(Supplier1)		1384(Supplier2)		1412(Supplier3)	

Table 11 Performance Evaluation Information of Multiple Suppliers in One Project

Figure 33 shows the system webpage that compares supplier performance evaluation result of multiple suppliers “Supplier1”, “Supplier2” and “Supplier3” in “Project7”.



	Delete Suppliers	Delete Suppliers	Delete Suppliers
Supplier Name	Supplier1	Supplier2	Supplier3
Contract Price	500000	10000	30000
SECV(Cost)	46	16	48
SECV(Quality)	34	36	48
SECV(Delivery)	52	48	36
SECV(Service)	50	60	52
SECV(Assurance of Supply)	38	56	48
SECV(Overall Ability)	60	72	48
SECV(Payment Terms)	28	24	32
SECV(Information Sharing)	30	28	32
SECV(Reputation)	50	52	64
SECV(Buyer-Supplier Relationship)	50	40	36
Average TECV	1400	1384	1412
Rank(Percentage)	2/3 (66.7%)	3/3 (100.0%)	1/3 (33.3%)

Figure 33 View the Comparison of Multiple Suppliers' Performance in One Project

From the general contractor's perspective, ASECV and ATECV may be the two most important reference data of a supplier's performance indicators. Higher ASECV and ATECV indicate better supplier performance on the project from the general contractor's perspective. From the result in Figure 33, "Supplier3" has the most ATECV and therefore can be considered to have the best performance among these 3 material suppliers. "Supplier1" has the least ATECV and therefore can be considered to have the worst performance among the 3 material suppliers in "Project7".

5.3.2.3 Compare One Supplier's Performance in Multiple Projects

If the performance evaluation of one supplier in several projects has been completed, then this system allows authorized performance evaluators to select one supplier and several project names to compare this supplier's performance evaluation results in the selected projects. Figure 34 shows one example that the supplier performance evaluator selects "Supplier1" and "Project2", "Project7" and "Project10" to compare this selected supplier's evaluation result in the selected projects.

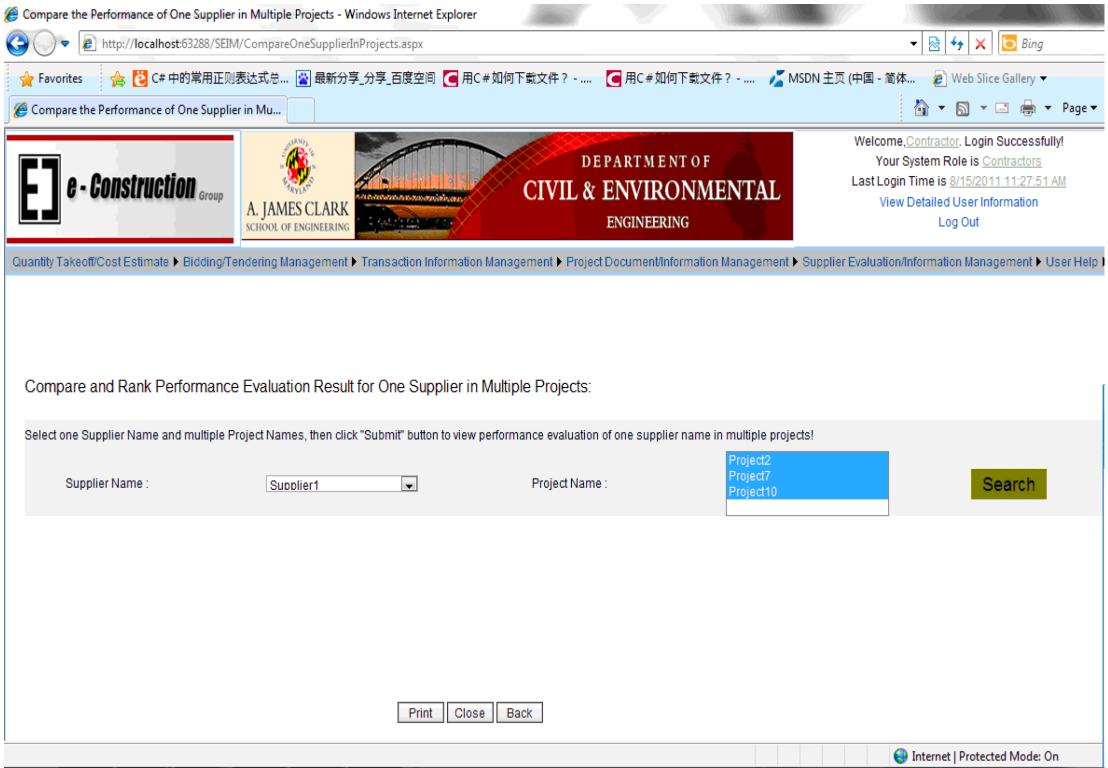


Figure 34 Choose One Supplier and Multiple Projects to Compare Performance

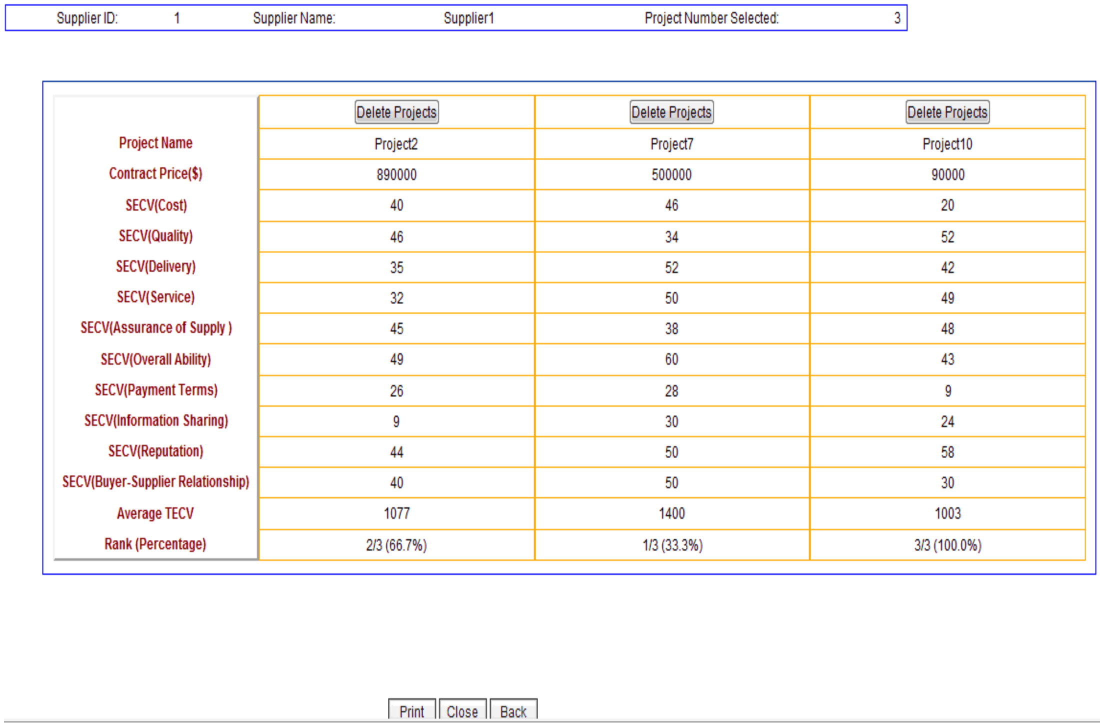
Table 12 shows the average evaluation information including ECV, PIV, ACV, ASECV and ATECV about “Supplier1” in “Project2”, “Project7” and “Project10” performed by all performance evaluators. The detailed supplier performance evaluation information and calculation results of “Supplier1” in “Project2” are shown in Table 10. The detailed supplier performance evaluation information and calculation results of “Supplier1” in “Project7” are shown in Table 11. Thus, Table 12 does not show the detailed ECV, PIV, and ACV of “Supplier1” in “Project2” or in “Project7”. Table 12 only shows the ECV, PIV, and ACV of “Supplier1” in “Project10”. All the data in ECV, PIV and ACV columns of “Project10” are inputted by the author randomly as the example. ASECV and ATECV are calculated based on the randomly inputted ECV, PIV and ACV. Other meanings of the abbreviated letters in Table 12 could make reference to Table 6 and Table 7 in Section 3.3. The calculation method of the data in Table 12 also references to the method list Function 1 to Function 7 in Section 3.3.

Project Name: Project2, Project7, Project10			**Supplier Name:** Supplier1		
Project10				**Project7**	**Project2**
ECV	**PIV**	**ACV**	**ASECV**	**ASECV**	**ASECV**
C (1)	TC 4)	1	20	46	40
	PS (1)	4			
	DR (3)	4			
O (4)	RR (5)	4	52	34	46

	FP (4)	5			
	AF (3)	4			
D (3)	LT (3)	5	42	52	35
	OTD 5)	3			
	DF (3)	4			
S (2)	SS (4)	3	49	50	32
	TAS (4)	3			
	CC (5)	5			
AS (1)	C (2)	4	48	38	45
	R (4)	5			
	F (4)	5			
OA (4)	TA (3)	3	43	60	49
	CBS (4)	3			
	MA (3)	4			
	PA (2)	5			
PT (5)	SP (4)	1	9	28	26
	PF (5)	1			
IS (1)	UEDA (5)	3	24	30	9
	WSSI (3)	3			
R(4)	CQ (4)	4	58	50	44
	AMDD (1)	5			
	CCI (5)	5			
	HC (3)	4			
BSR(1)	GC (4)	3	30	50	40
	CM (4)	2			
	PFR (5)	2			
ATECV		1003(Project10)		1400 (Project7)	1077 (Project2)

Table 12 Performance Evaluation Information of One Supplier in Multiple Projects

Figure 35 is the system webpage of “Supplier 1” performance comparison in “Project2”, “Project7” and “Project10”.



Supplier ID:	1	Supplier Name:	Supplier1	Project Number Selected:	3

	Delete Projects	Delete Projects	Delete Projects
Project Name	Project2	Project7	Project10
Contract Price($)	890000	500000	90000
SECV(Cost)	40	46	20
SECV(Quality)	46	34	52
SECV(Delivery)	35	52	42
SECV(Service)	32	50	49
SECV(Assurance of Supply)	45	38	48
SECV(Overall Ability)	49	60	43
SECV(Payment Terms)	26	28	9
SECV(Information Sharing)	9	30	24
SECV(Reputation)	44	50	58
SECV(Buyer-Supplier Relationship)	40	50	30
Average TECV	1077	1400	1003
Rank (Percentage)	2/3 (66.7%)	1/3 (33.3%)	3/3 (100.0%)

Figure 35 Comparison of Performance Evaluation of One Supplier in Multiple Projects

From the results of Figure 35, "Supplier1" has most ATECV in "Project7" and can be considered to have the best performance in "Project7" among the 3 selected projects, and "Supplier1" has the least ATECV in "Project10" and can be considered to have the least performance in "Project10" among the 3 selected projects.

5.3.2.4 Usage of Supplier Performance Evaluation Information

All supplier performance evaluation records can be saved to system database. These records form a preliminary historical supplier performance information database for each material supplier. Information concerning these records can be reviewed by all supplier performance evaluators within their access rights in the future and can work as the historical reference data for general contractors to make supplier selection in the future projects.

6 Conclusions and Future Research

6.1 Conclusions

Based on the comprehensive literature review on e-commerce and BIM in construction quantity takeoff, cost estimate and material procurement, and supplier evaluation criteria and methods, and persistent efforts in software design, development and integration, the author presented a framework and displayed one development solution to integrate BIM and e-commerce in quantity takeoff, cost estimate, material procurement and material supplier evaluation and information management. This research makes innovations in the followings aspects:

- The author applied BIM in material quantity takeoff based on Autodesk Revit development platform, and linked quantity takeoff data with RSMeans Unit Price material cost criterion data to generate material cost estimate report, which is different from commercial quantity takeoff software such as QTO, Innovaya Visual Quantity Takeoff, Tocoman Quantity Takeoff and Vico Takeoff. Cost information generated in this platform will have better accuracy over traditional cost estimate methods and will provide a better cost standard for the future supplier quote evaluation and supplier selection.

- The author presented a practical framework and developed a display version of software system to integrate BIM in material quantity takeoff and cost estimate, e-commerce in material procurement activities including bidding, tendering, awarding, transaction history management and supplier performance evaluation and management, which has never been explored by other researcher before.

- The author proposed a series of applicable supplier performance evaluation criteria and an evaluation method using weight coefficient, which provides practical value on future supplier performance evaluation and selection in e-procurement process.

6.2 Future Research

Future research will focus on the following aspects:

- Research on the improvement of BIM integrated with e-commerce framework in the material quantity takeoff, cost estimate, procurement process and supplier performance evaluation. More detailed workflow, module definition, user role definition, data flow and technical implementation about this framework should be studied in the future research.

- Research on identification and analysis of cost, benefit and risk factors will provide useful data and reference for the decision-making in software design and development. Although many literatures have explored the cost, benefit and risk of E-Commerce and BIM in construction, there is no ongoing research on the potential cost, benefit and risk factors of BIM integrated with E-Commerce software system application in quantity takeoff, cost estimate, material procurement process and supplier performance evaluation and information management. Therefore, research on potential cost, benefit and risk analysis of BIM integrated with E-Commerce software system application in material quantity takeoff, cost estimate and material procurement process will be of practical value for future software vendors to design and develop software system.

- Computer Supported Cooperative Work (CSCW) is the technology which combines the understanding of the way people work in groups with the enabling technologies of computer networking, and associated hardware, software, services and techniques (Kamel and Davison, 1998). BIM includes a database that comprises computer three-dimensional models and provides high possibility for project members from various professional backgrounds to share the same data and work with the same model. BIM requires participants to develop closer relationships with key team members, foster the open exchange of electronic information, and encourage closer collaboration than ever. BIM introduces new team dynamics, accelerated decision-making, and complexities that demand a strong working relationship (Eos Group, 2008), so BIM is more suitable for cooperative work mode. Therefore, future work may concentrate on the framework of BIM, E-Commerce and CSCW software integration solution in construction material procurement process.

- Material quantity takeoff, cost estimate, material procurement and supplier performance evaluation and information management are parts of issues of construction project lifecycle management, so the proposed framework and developed software system in this paper should be integrated with other construction project lifecycle management software systems to streamline material procurement workflow and optimize system benefit. One potential future research is the integration and optimization of this proposed framework and system with present web-based Project Management or Enterprise Resource Planning (ERP) systems in construction firms.

Appendices

Content from Appendix 1 to Appendix 8 includes different examples of system interfaces of BIM integrated with e-commerce software system. System interfaces that have been displayed in 5.3 Case Study part will not be shown in the Appendices Section.

Appendix 1. Enter Software System and Choose System Interface

1) Log into Software System with User Name and Password

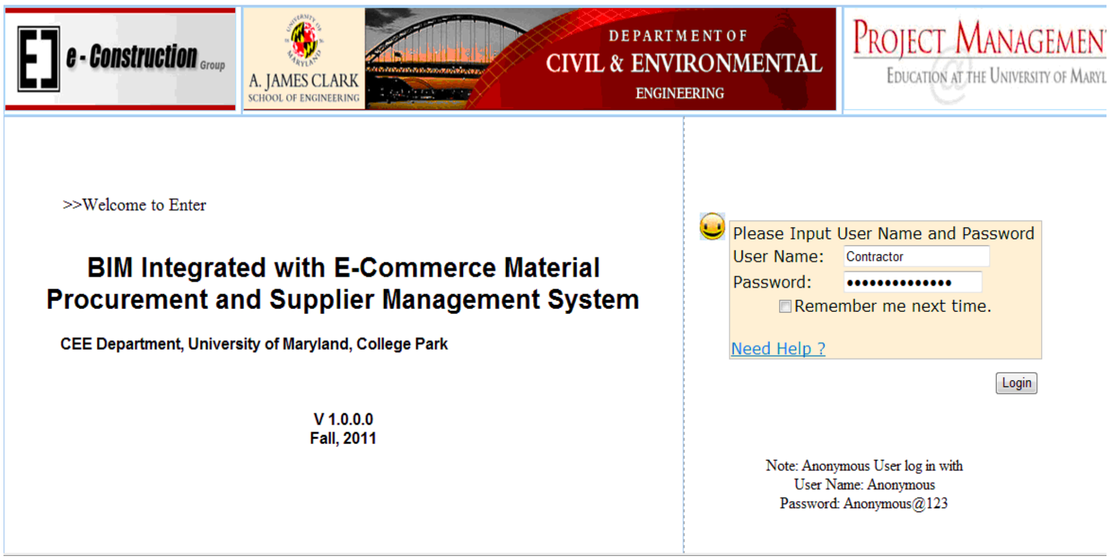


Figure 36 Log into Software System with User Name and Password

2) Choose to Enter a System Function

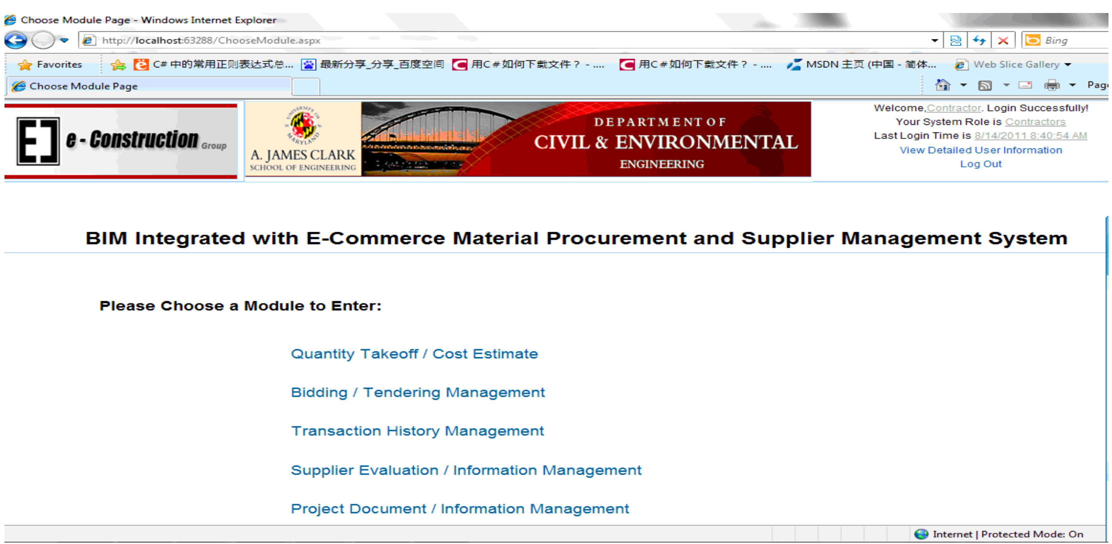


Figure 37 Choose to Enter a System Function

3) Quantity Takeoff - Cost Estimate Function

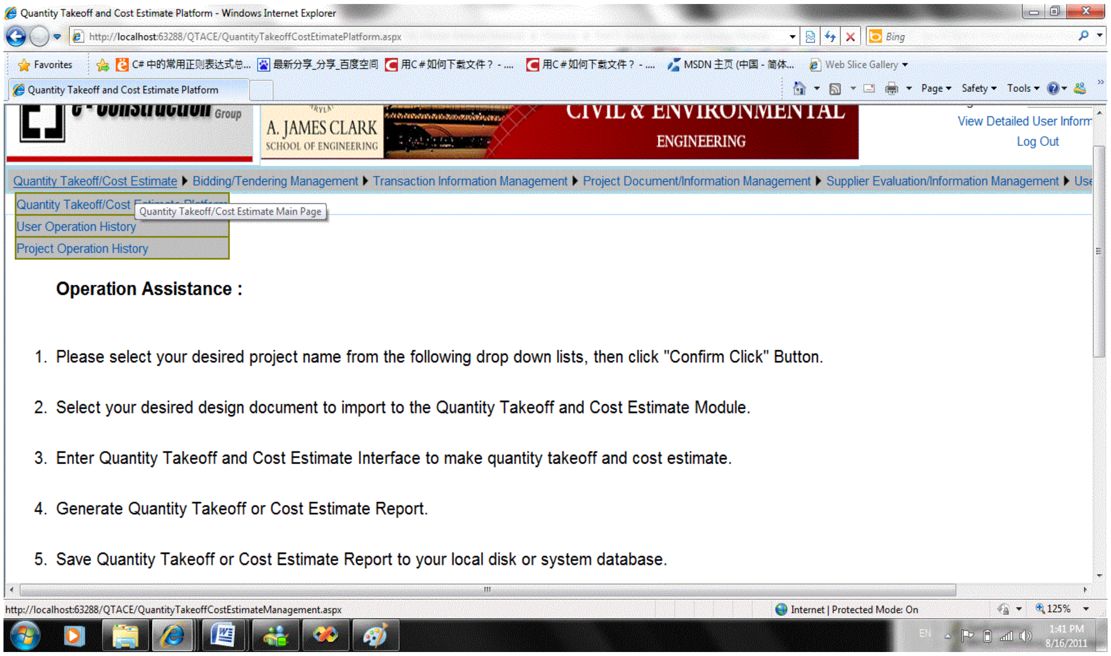


Figure 38 Quantity Takeoff - Cost Estimate Functions

4) Bidding and Tendering Management Function

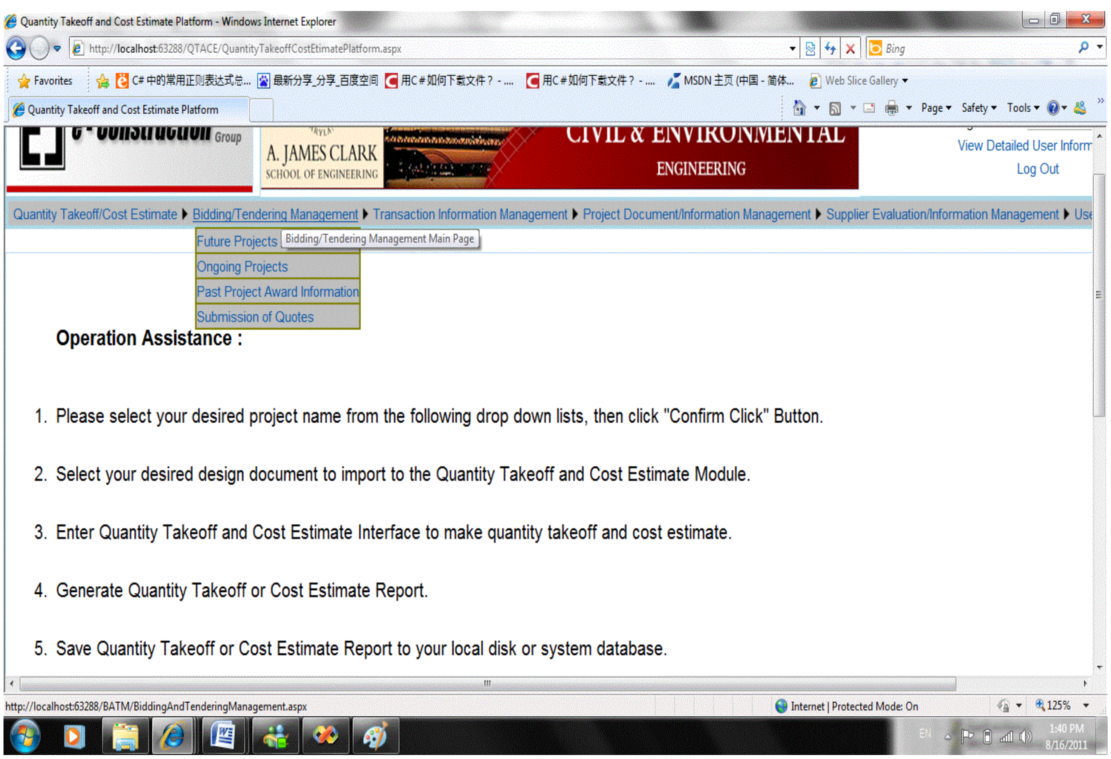


Figure 39 Bidding and Tendering Management Function

5) Transaction History Information Management Function

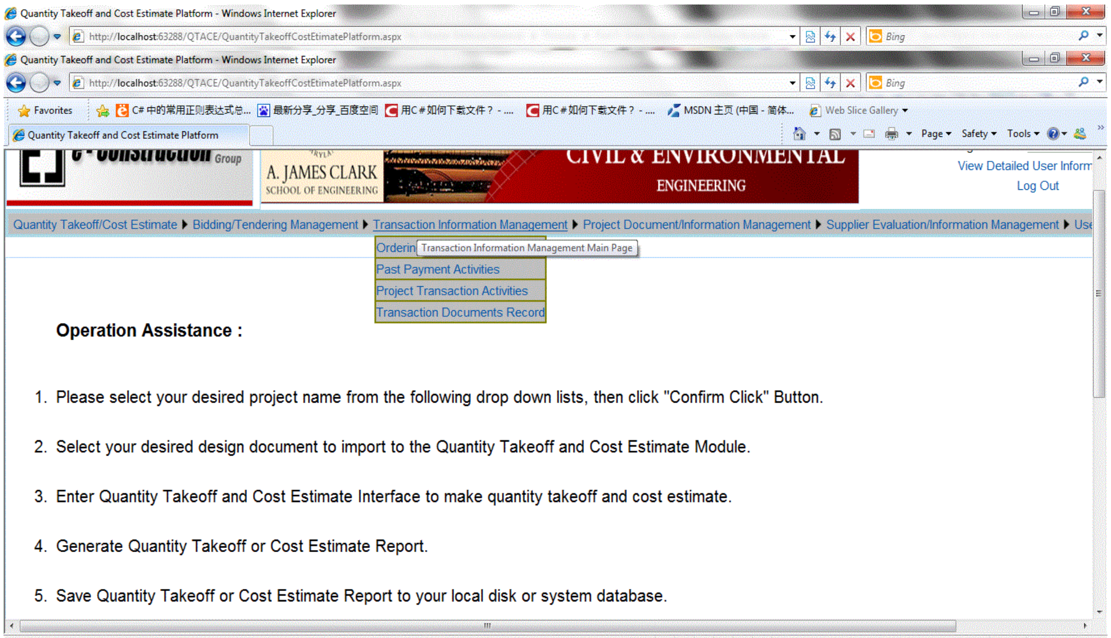


Figure 40 Transaction History Information Management Function

6) Project Document and Information Management Function

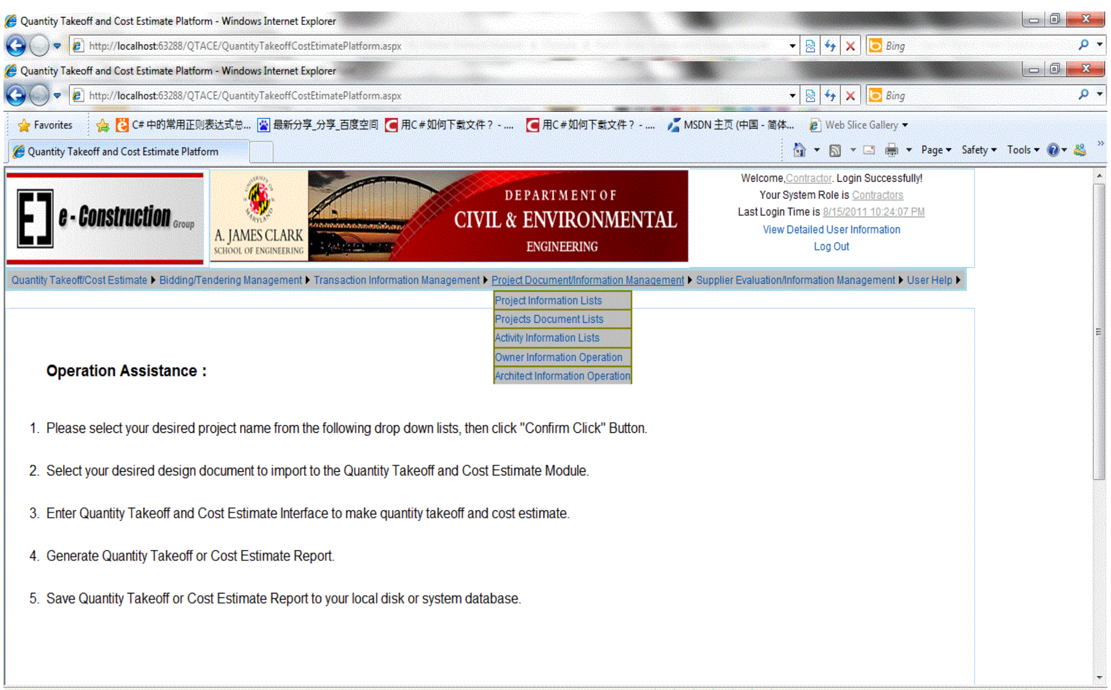


Figure 41 Project Document and Information Management Function

7) Supplier Performance Evaluation and Information Management Function

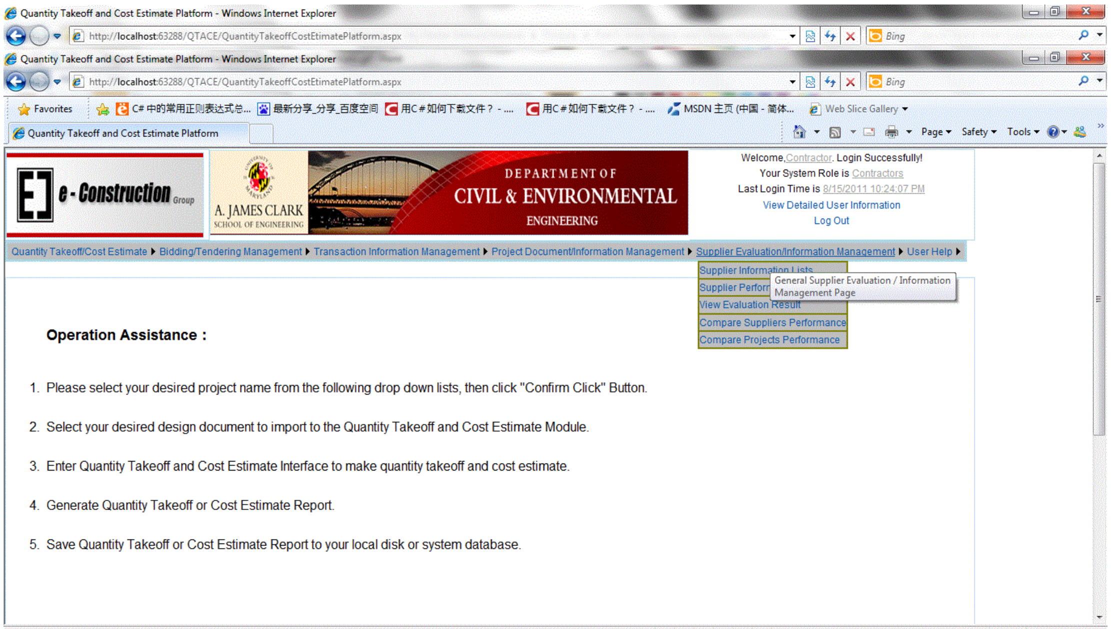


Figure 42 Supplier Performance Evaluation and Information Management Function

8) User Help Function

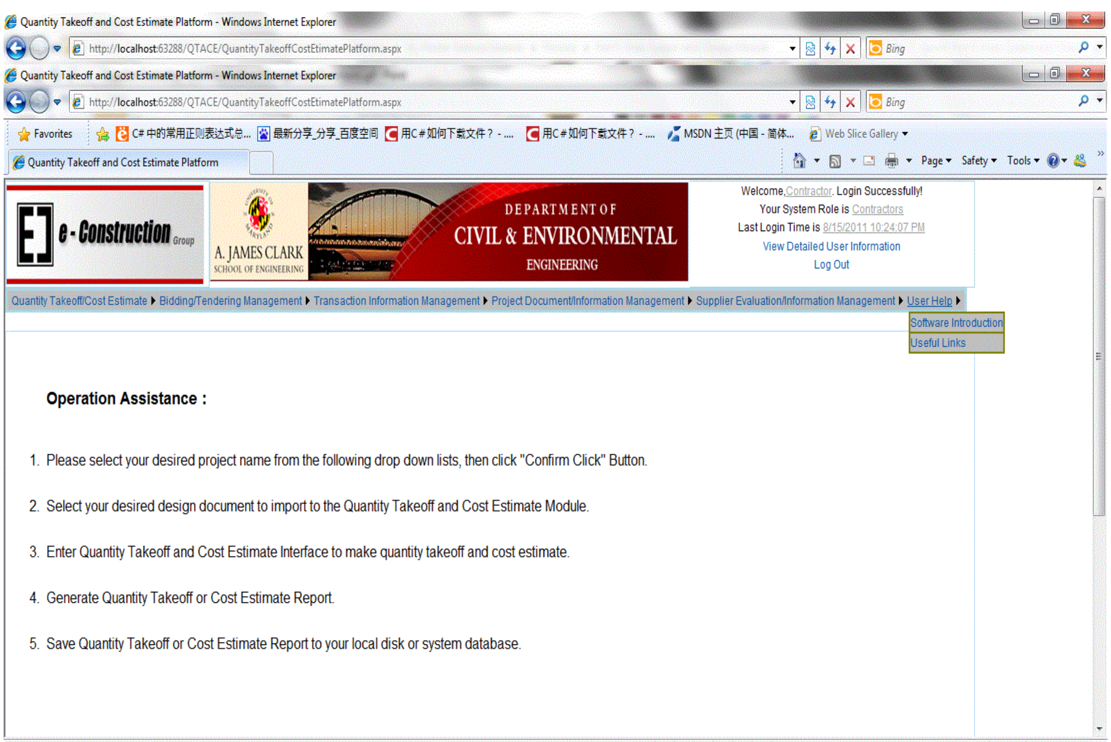


Figure 43 User Help Function

Appendix 2. Material Quantity Takeoff and Cost Estimate Interface

1) View Project Material Quantity Takeoff / Cost Estimate History

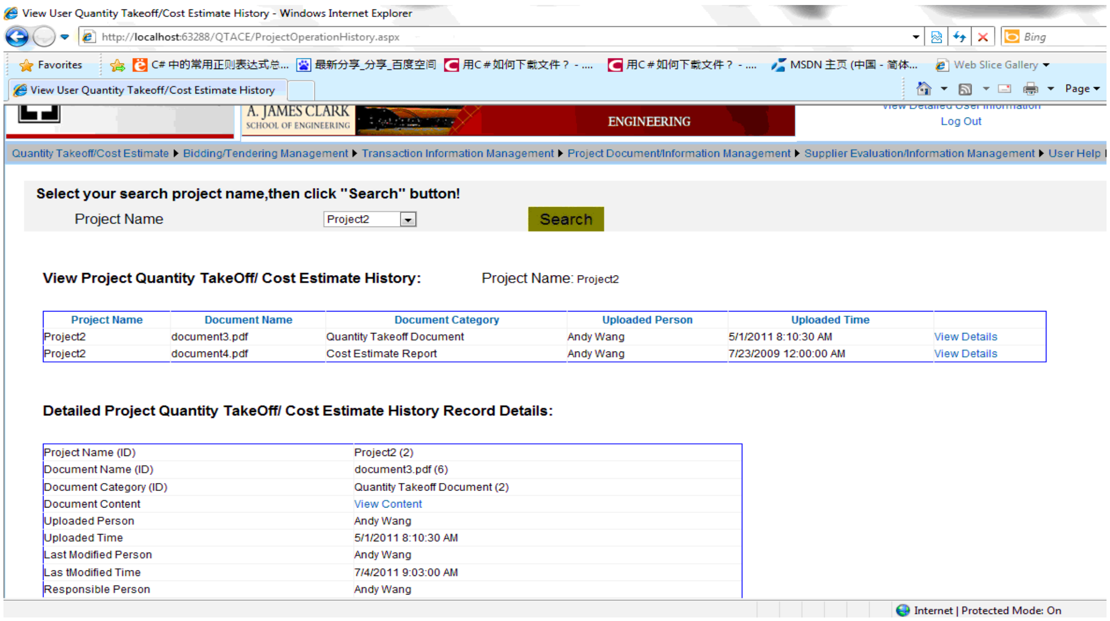


Figure 44 View Project Material Quantity Takeoff / Cost Estimate History

Appendix 3. Bidding and Tendering Interface

1) Bidding and Tendering Management Introduction Page

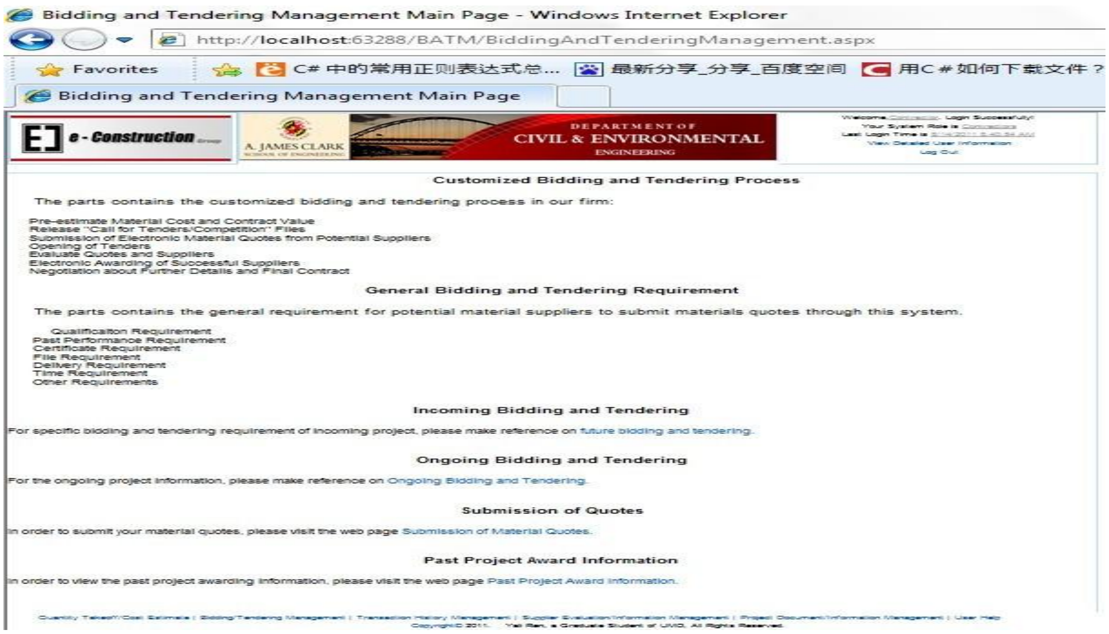


Figure 45 Bidding and Tendering Management Introduction Page

2) Future Bidding and Tendering Project Information Page

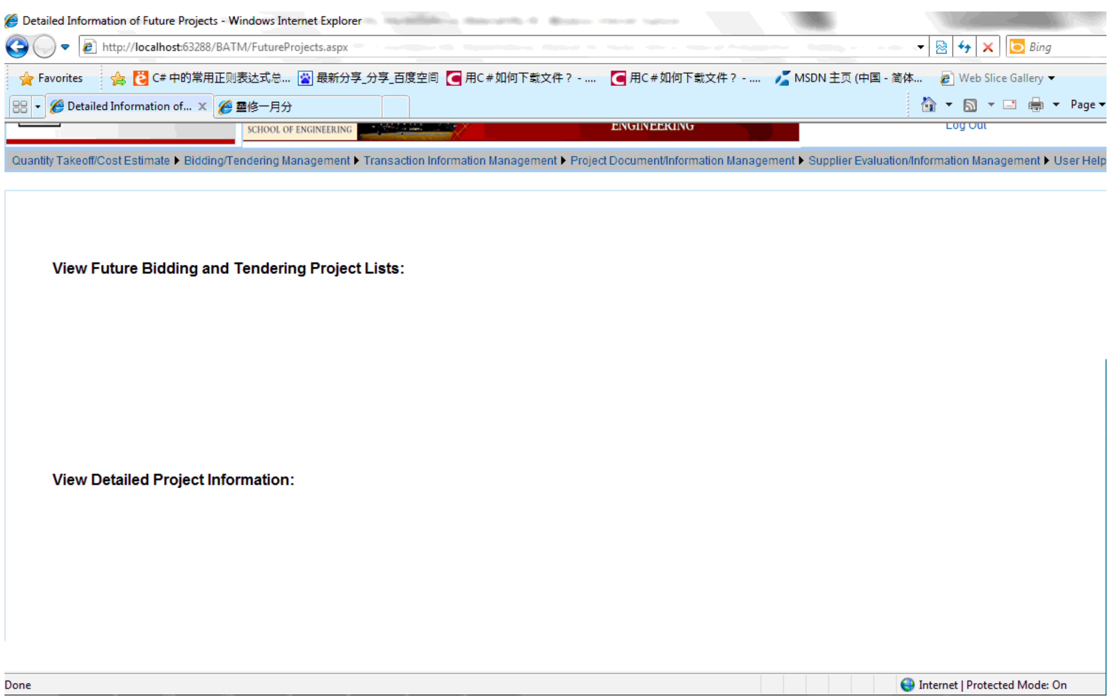


Figure 46 Future Bidding and Tendering Project Information Page

3) Ongoing Bidding and Tendering Project Information Page

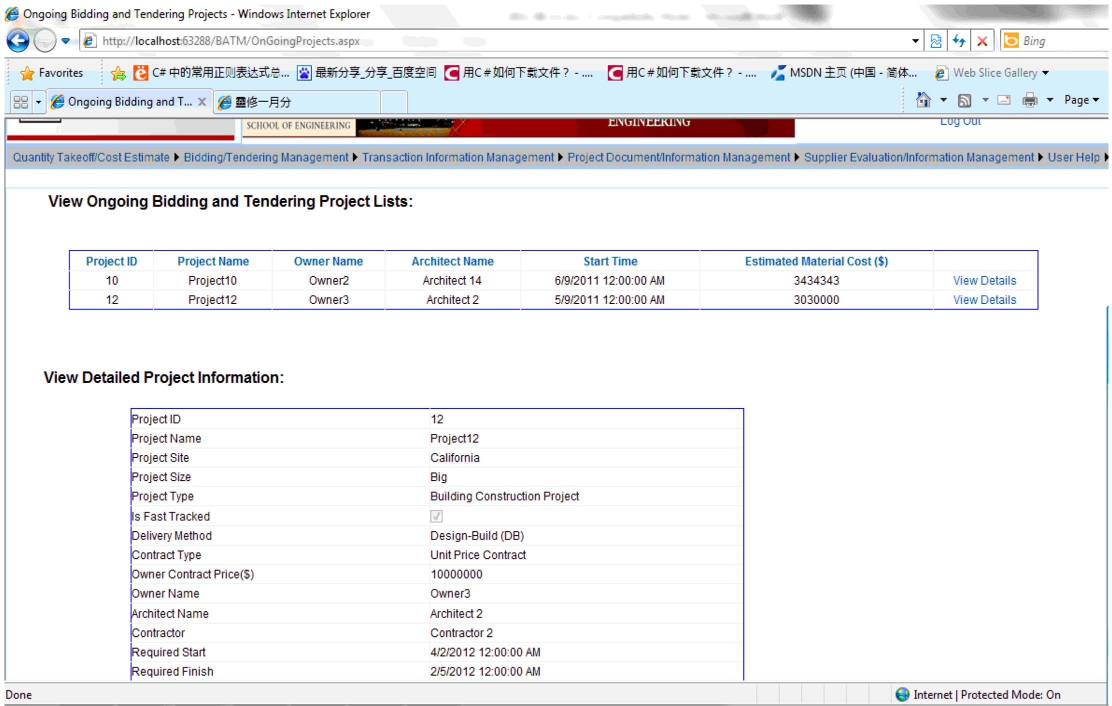


Figure 47 Ongoing Bidding and Tendering Project Information Page

4) Past Project Award Information Page

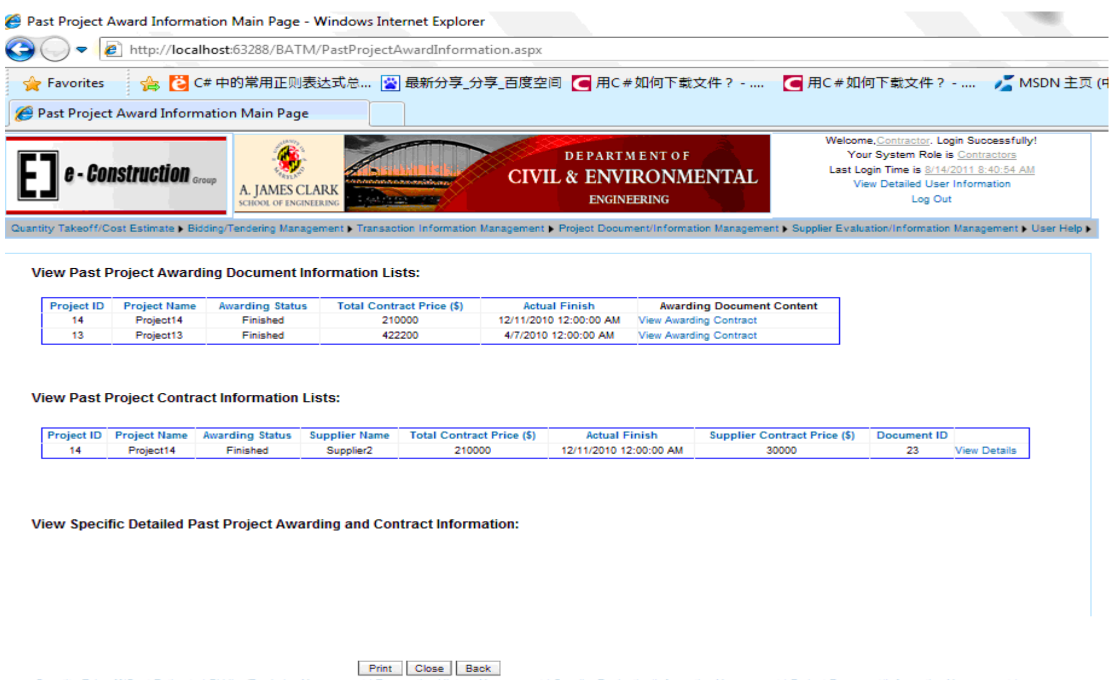


Figure 48 Past Project Award Information Page

5) Submission of Material Quotes Page

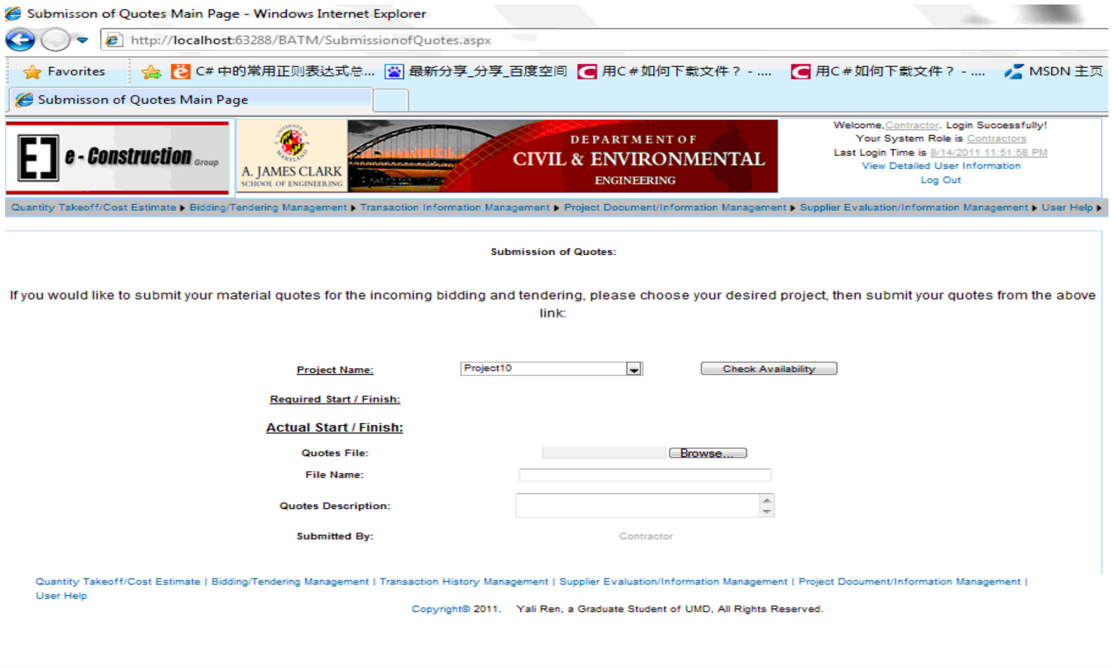


Figure 49 Submission of Material Quotes Page

Appendix 4. Transaction History Management Interface

1) Material Cost Electronic Payment Page

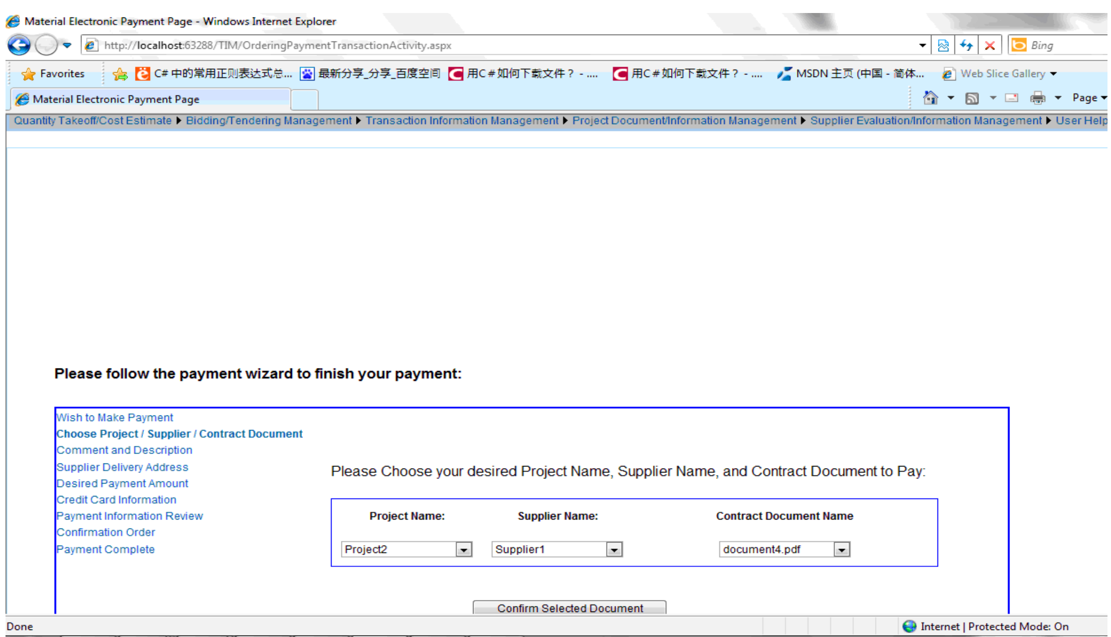
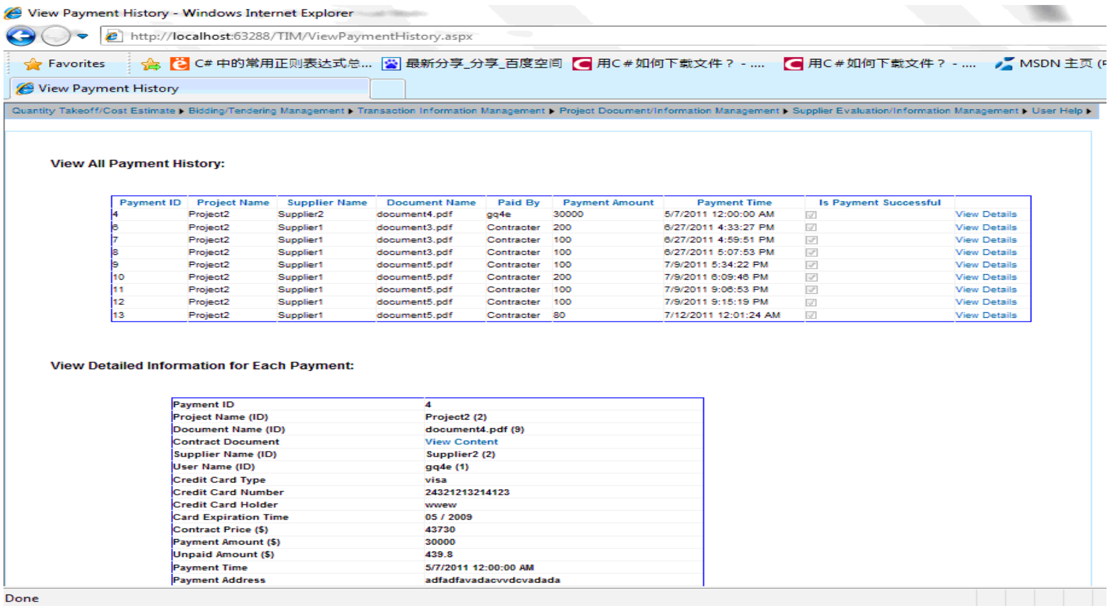


Figure 50 Material Cost Electronic Payment Page

2) Page to View Past Material Cost E-Payment Activities Information

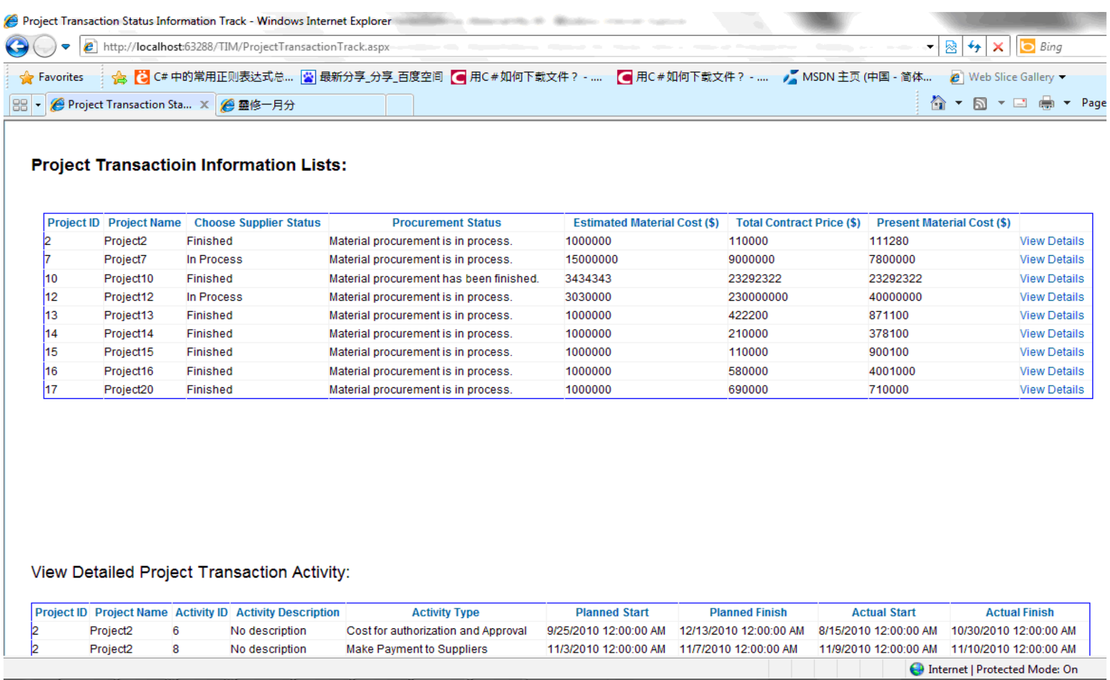


Payment ID	Project Name	Supplier Name	Document Name	Paid By	Payment Amount	Payment Time	Is Payment Successful	
4	Project2	Supplier2	document4.pdf	gq4e	30000	5/7/2011 12:00:00 AM	☑	View Details
6	Project2	Supplier1	document3.pdf	Contracter	200	6/27/2011 4:33:27 PM	☑	View Details
7	Project2	Supplier1	document3.pdf	Contracter	100	6/27/2011 4:59:51 PM	☑	View Details
8	Project2	Supplier1	document3.pdf	Contracter	100	6/27/2011 5:07:53 PM	☑	View Details
9	Project2	Supplier1	document5.pdf	Contracter	100	7/9/2011 5:34:22 PM	☑	View Details
10	Project2	Supplier1	document5.pdf	Contracter	200	7/9/2011 6:09:46 PM	☑	View Details
11	Project2	Supplier1	document5.pdf	Contracter	100	7/9/2011 9:06:53 PM	☑	View Details
12	Project2	Supplier1	document5.pdf	Contracter	100	7/9/2011 9:15:19 PM	☑	View Details
13	Project2	Supplier1	document5.pdf	Contracter	80	7/12/2011 12:01:24 AM	☑	View Details

Payment ID	4
Project Name (ID)	Project2 (2)
Document Name (ID)	document4.pdf (9)
Contract Document	View Content
Supplier Name (ID)	Supplier2 (2)
User Name (ID)	gq4e (1)
Credit Card Type	visa
Credit Card Number	24321213214123
Credit Card Holder	wwew
Card Expiration Time	05 / 2009
Contract Price ($)	43730
Payment Amount ($)	30000
Unpaid Amount ($)	439.8
Payment Time	5/7/2011 12:00:00 AM
Payment Address	adfadfavadacvvdcvadada

Figure 51 Page to View Past Material Cost E-Payment Activities Information

3) Page to View Past Project Transaction Activity Information



Project ID	Project Name	Choose Supplier Status	Procurement Status	Estimated Material Cost ($)	Total Contract Price ($)	Present Material Cost ($)	
2	Project2	Finished	Material procurement is in process.	1000000	110000	111280	View Details
7	Project7	In Process	Material procurement is in process.	15000000	9000000	7800000	View Details
10	Project10	Finished	Material procurement has been finished.	3434343	23292322	23292322	View Details
12	Project12	In Process	Material procurement is in process.	3030000	230000000	40000000	View Details
13	Project13	Finished	Material procurement is in process.	1000000	422200	871100	View Details
14	Project14	Finished	Material procurement is in process.	1000000	210000	378100	View Details
15	Project15	Finished	Material procurement is in process.	1000000	110000	900100	View Details
16	Project16	Finished	Material procurement is in process.	1000000	580000	4001000	View Details
17	Project20	Finished	Material procurement is in process.	1000000	690000	710000	View Details

Project ID	Project Name	Activity ID	Activity Description	Activity Type	Planned Start	Planned Finish	Actual Start	Actual Finish
2	Project2	6	No description	Cost for authorization and Approval	9/25/2010 12:00:00 AM	12/13/2010 12:00:00 AM	8/15/2010 12:00:00 AM	10/30/2010 12:00:00 AM
2	Project2	8	No description	Make Payment to Suppliers	11/3/2010 12:00:00 AM	11/7/2010 12:00:00 AM	11/9/2010 12:00:00 AM	11/10/2010 12:00:00 AM

Figure 52 Page to View Past Project Transaction Activity Information

4) Query of Transaction Document Related Information Page

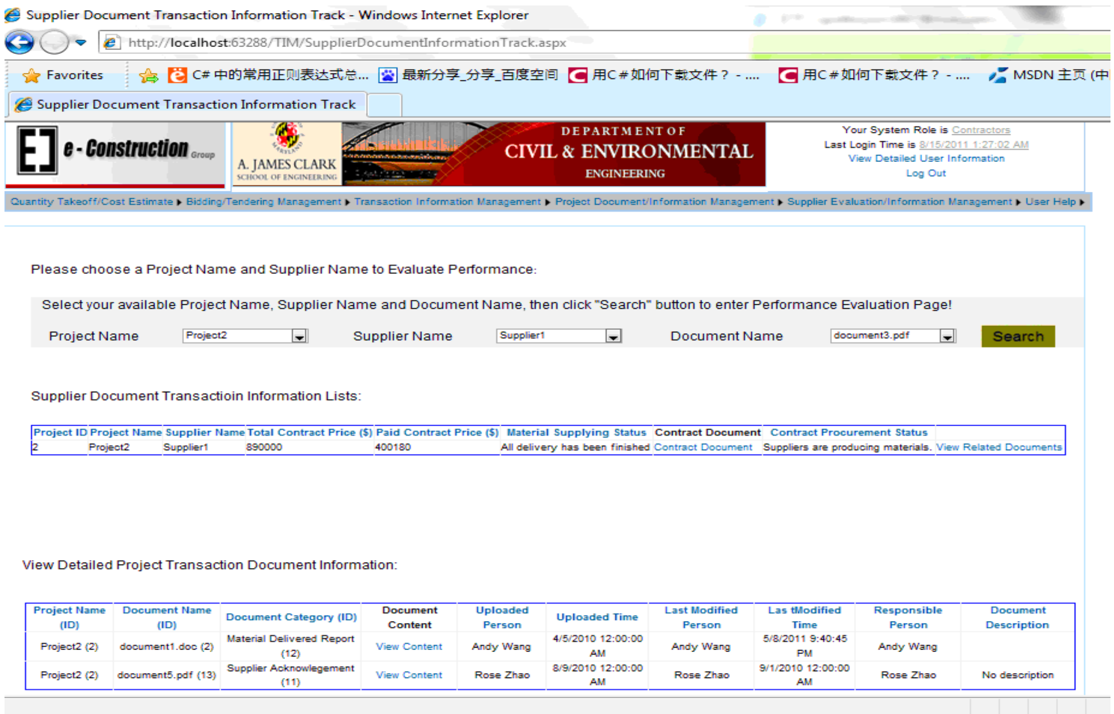


Figure 53 Query of Transaction Document Related Information Page

Appendix 5. Project Document and Information Management Interface

1) Project Information List Interface

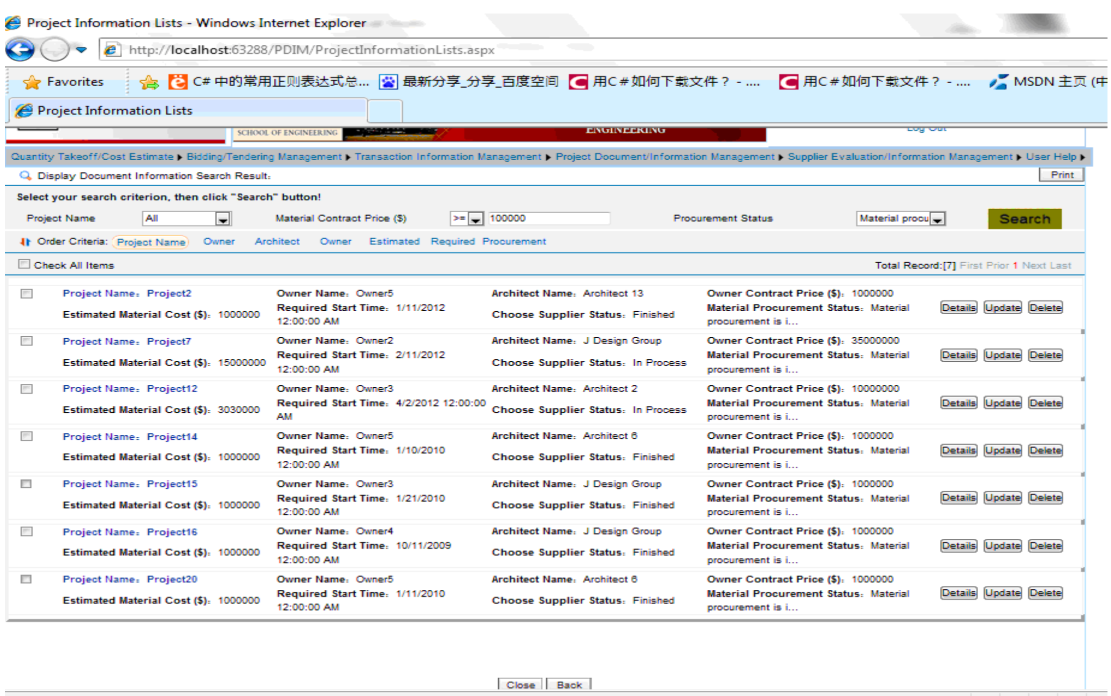


Figure 54 Project Information List Page

2) Alert to View Detailed Project Information

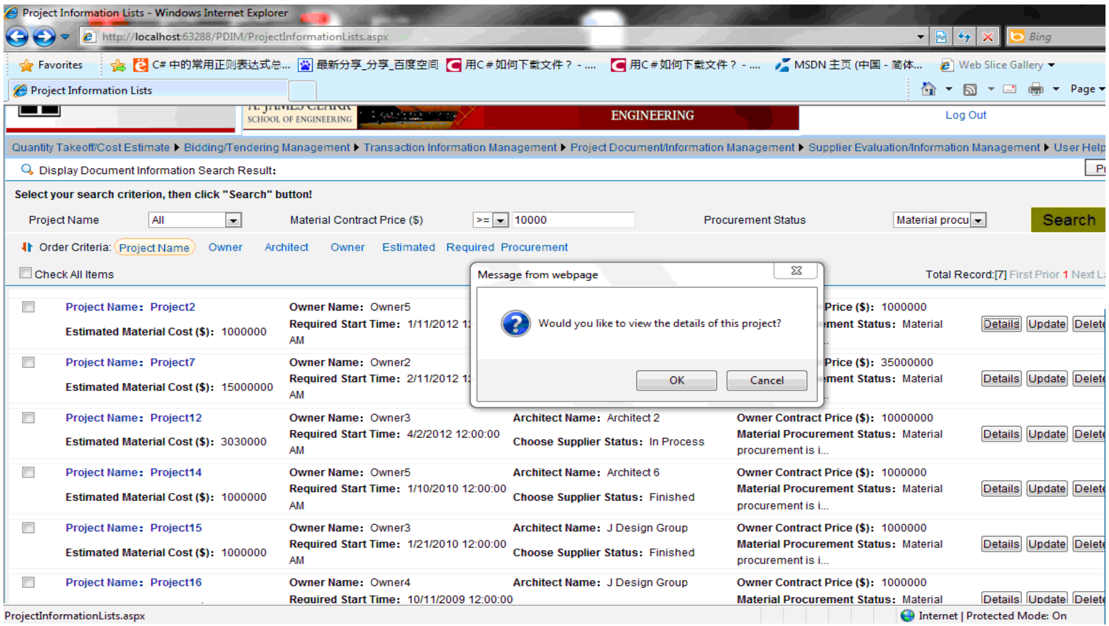


Figure 55 Alert to View Detailed Project Information

3) Alert to Modify Detailed Project Information

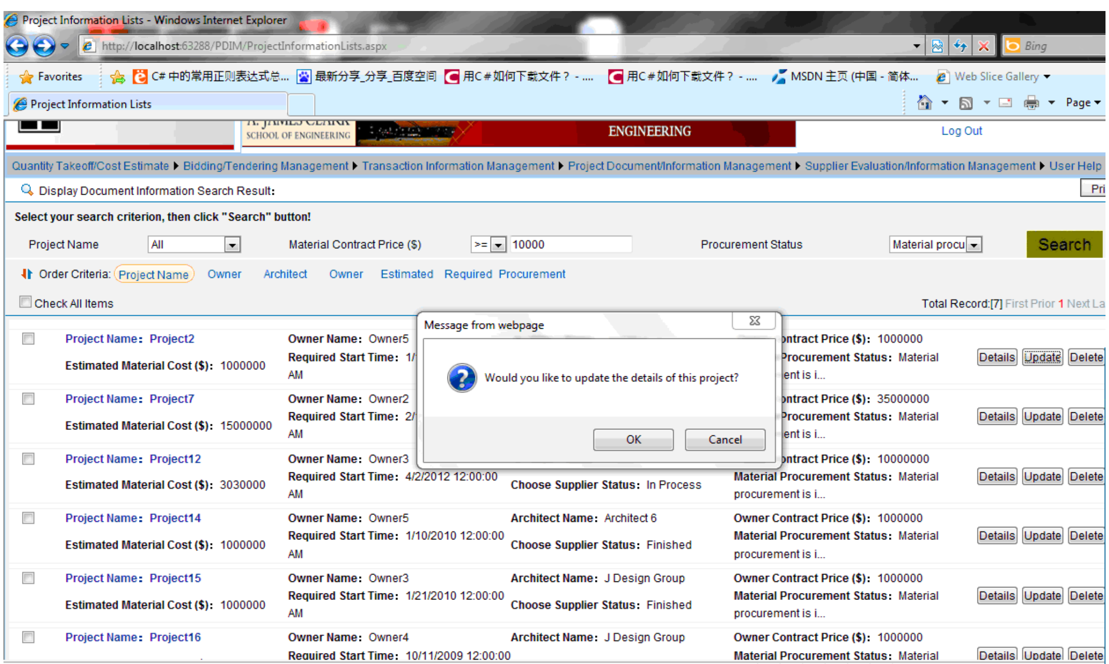


Figure 56 Alert to Modify Detailed Project Information

4) Alert to Delete One Specific Project Information

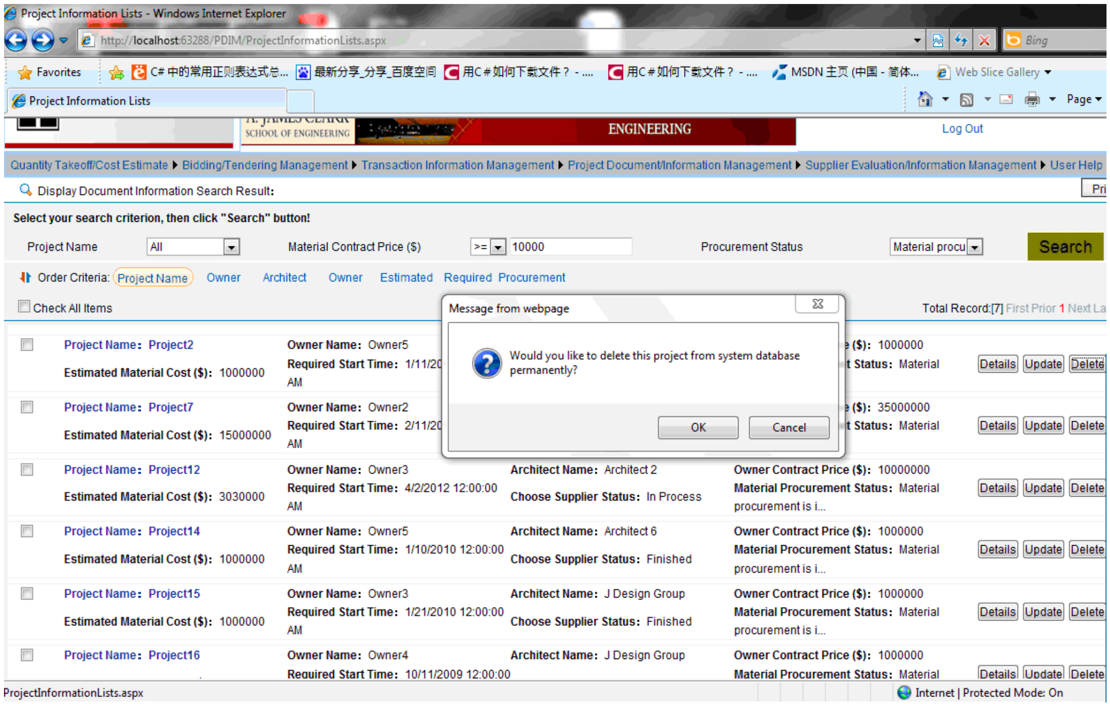


Figure 57 Alert to Delete One Specific Project Information

5) Print Project Information List Page

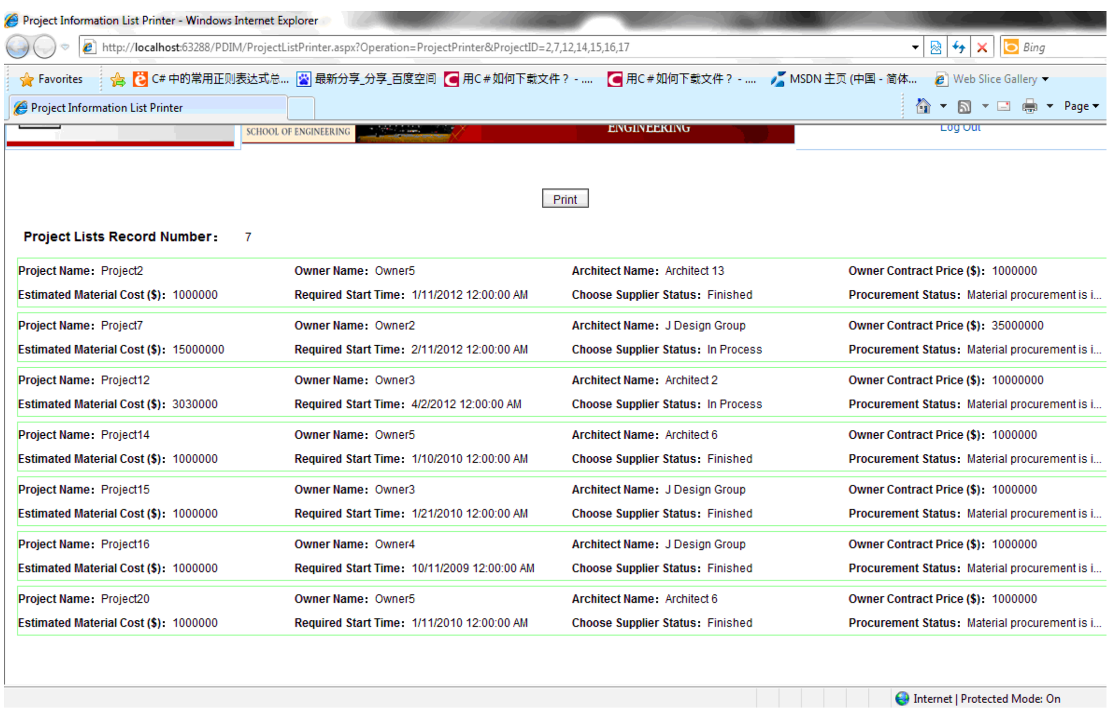


Figure 58 Print Project Information List Page

6) Detailed One Project Information

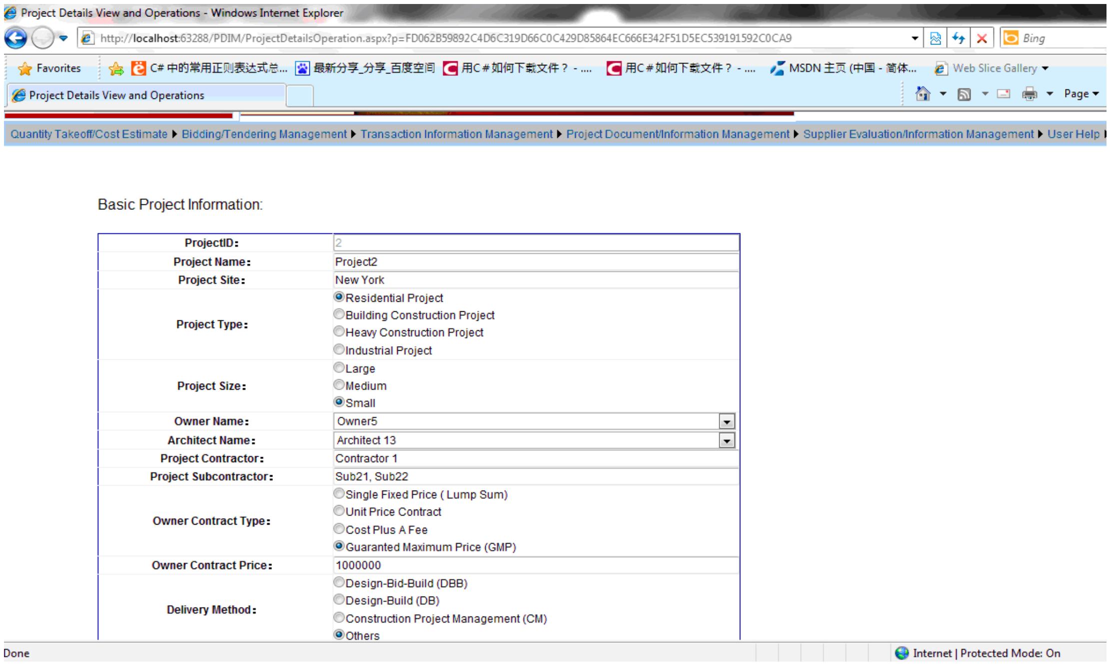


Figure 59 Detailed One Project Information

7) Detailed Owner Information of One Project

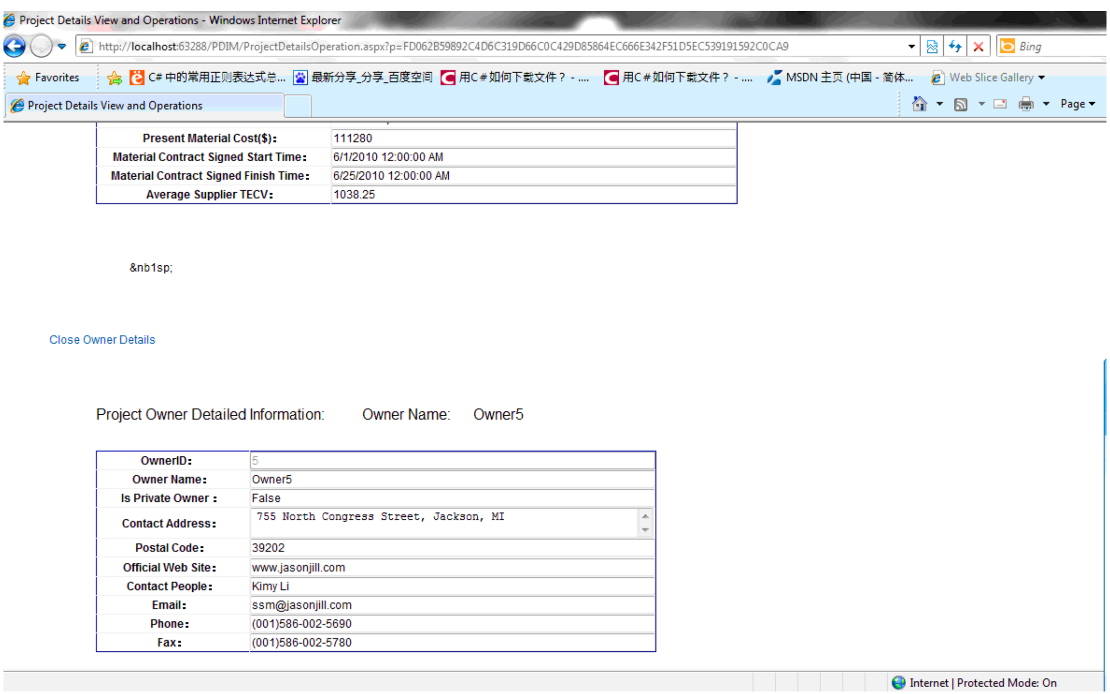


Figure 60 Detailed Owner Information of One Project

8) Detailed Owner and Architect Information of One Project

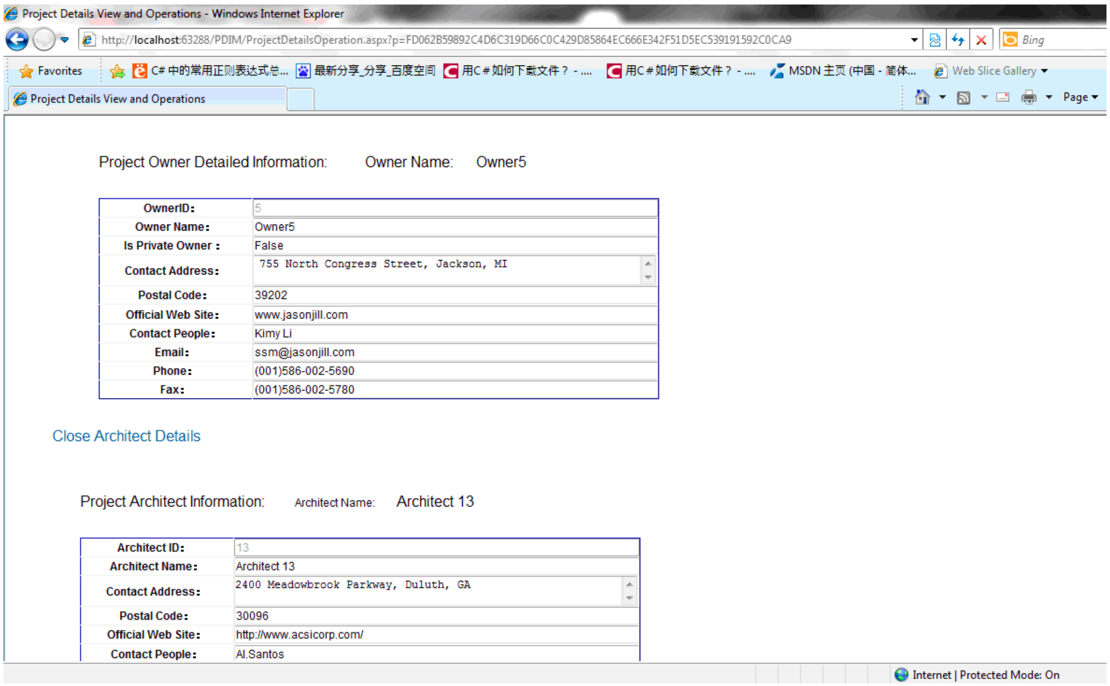


Figure 61 Detailed Owner and Architect Information of One Project

9) Detailed Supplier Information of One Project

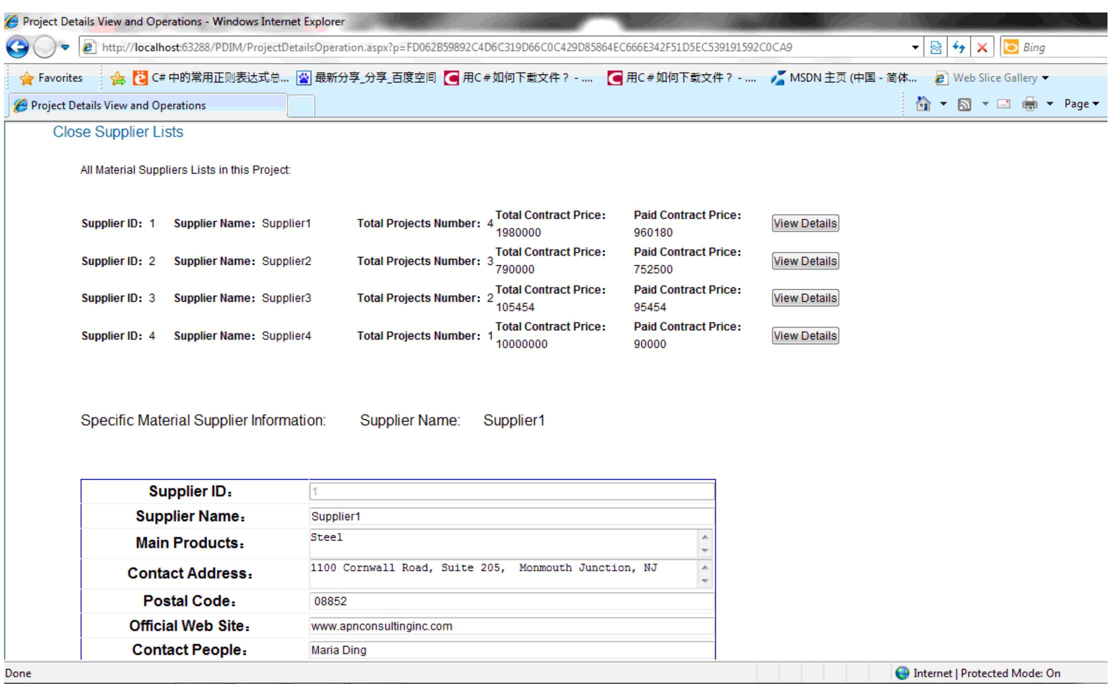


Figure 62 Detailed Supplier Information of One Project

10) Modify, Add Project Information and Change Project Owner

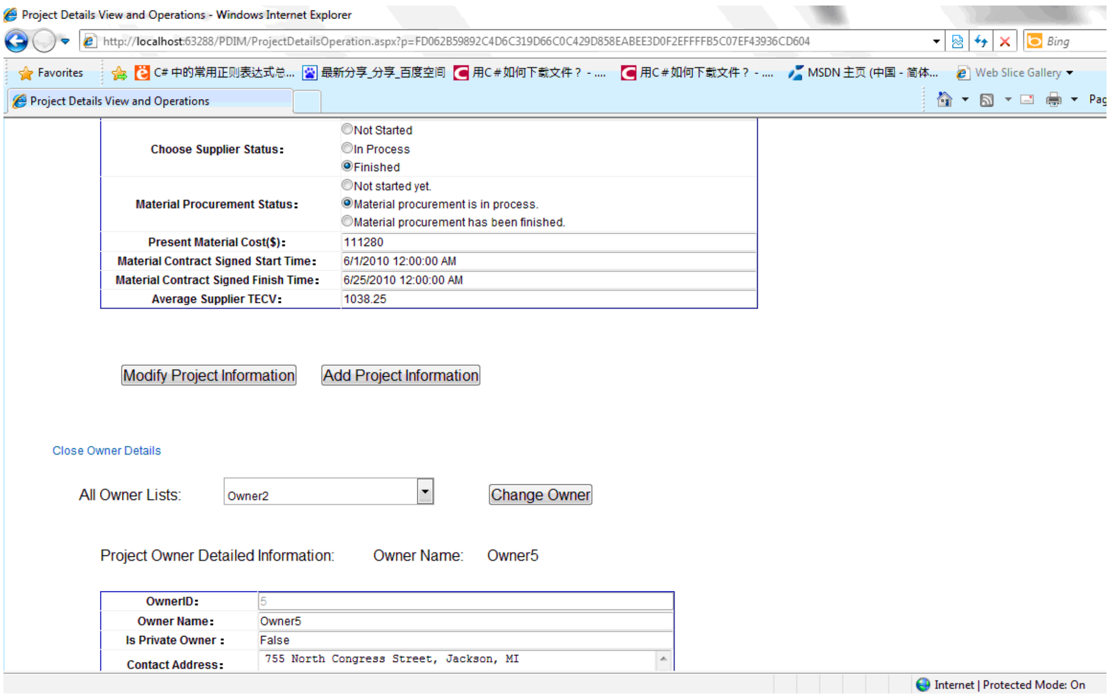


Figure 63 Modify, Add Project Information and Change Project Owner

11) Change Architect, Add or Delete Supplier Information of One Project

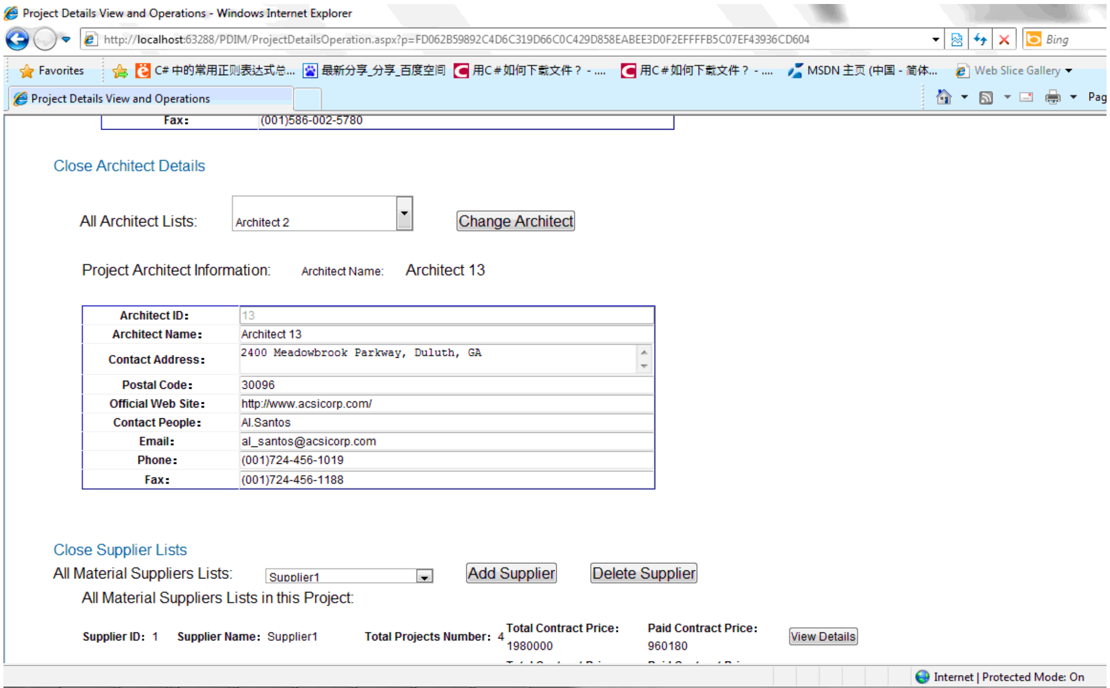


Figure 64 Change Architect, Add or Delete Supplier Information of One Project

12) Document Information List Page

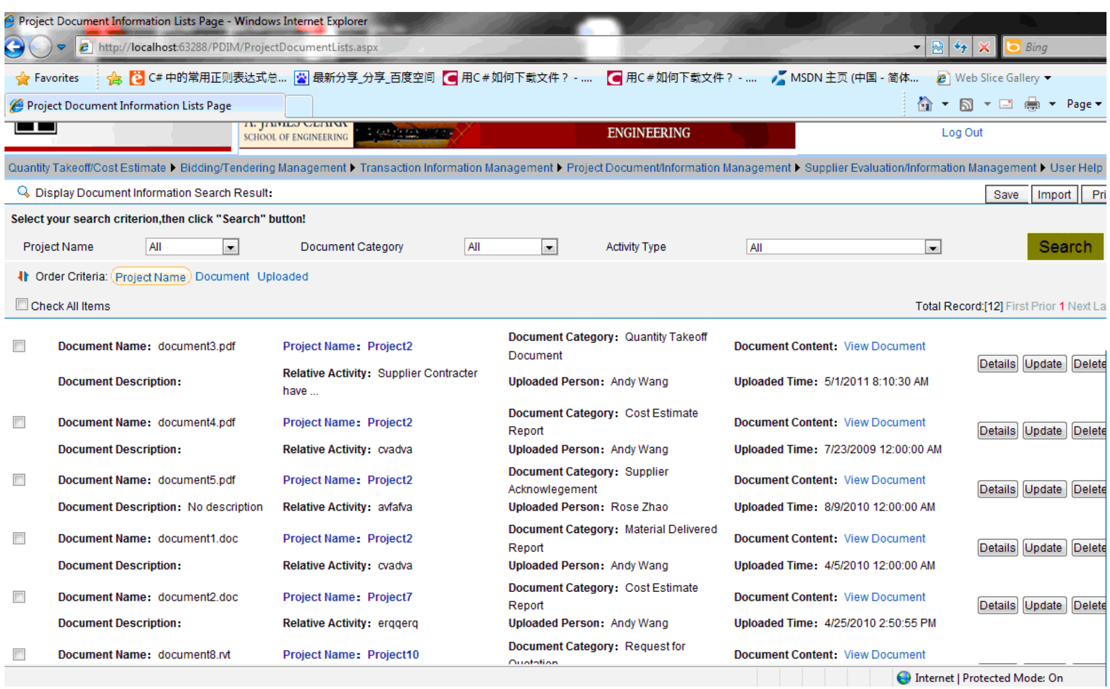


Figure 65 Document Information List Page

13) Alert to View Detailed Document Information

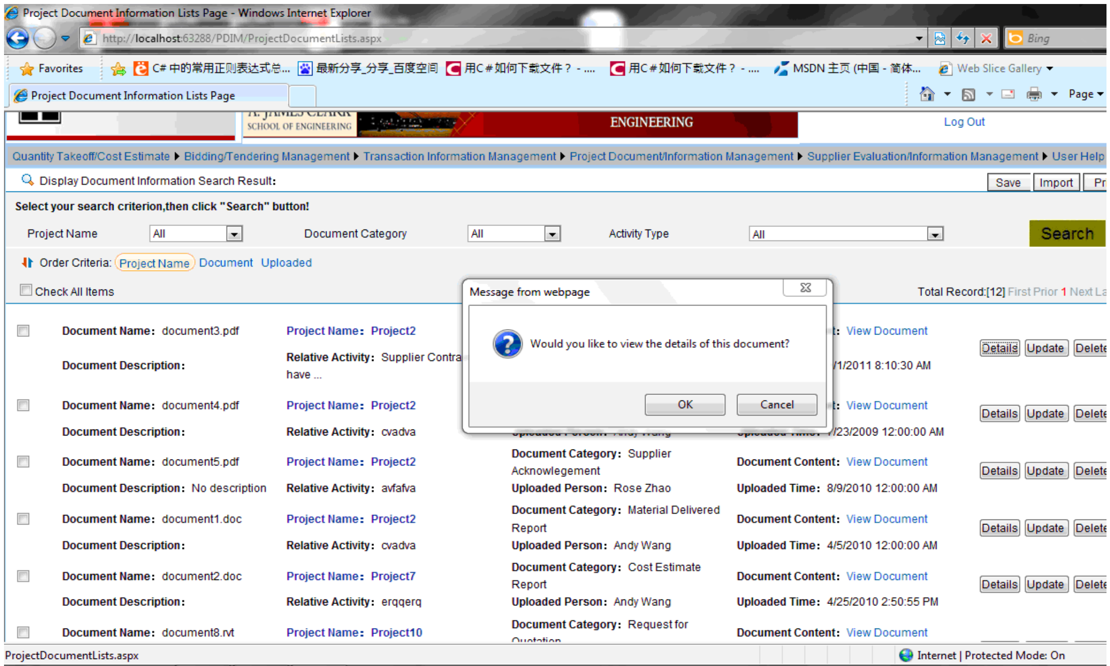


Figure 66 Alert to View Detailed Document Information

14) Alert to Modify Detailed Document Information

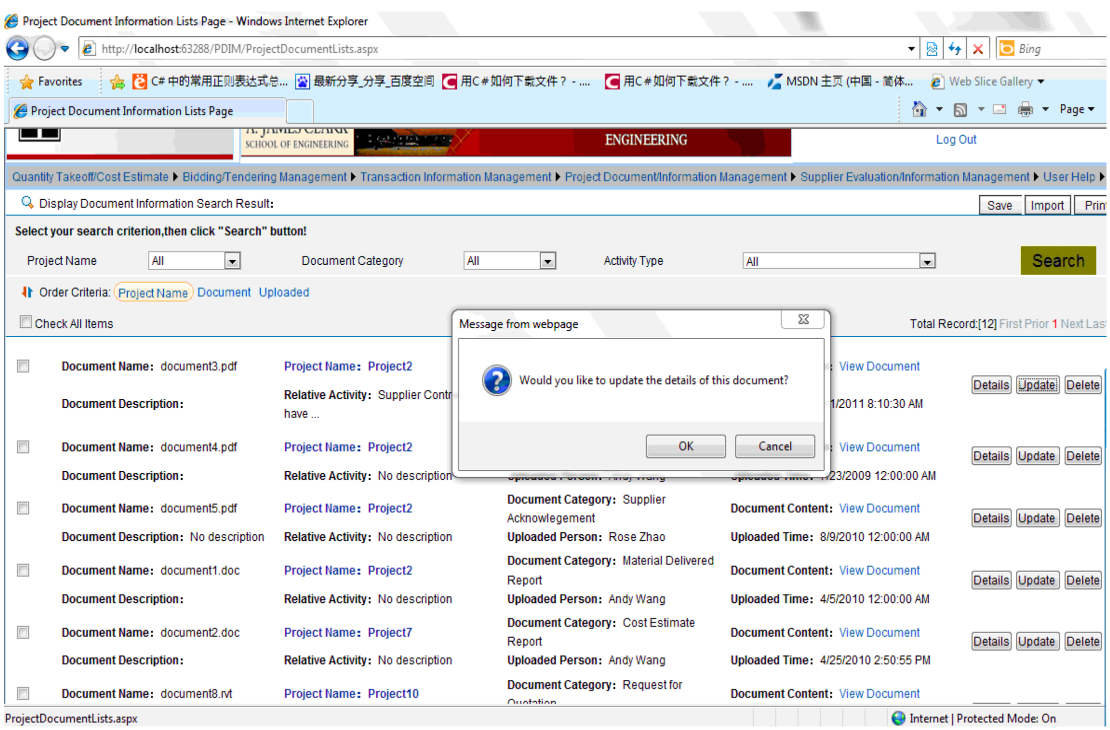


Figure 67 Alert to Modify Detailed Document Information

15) Alert to Delete One Specific Document Information

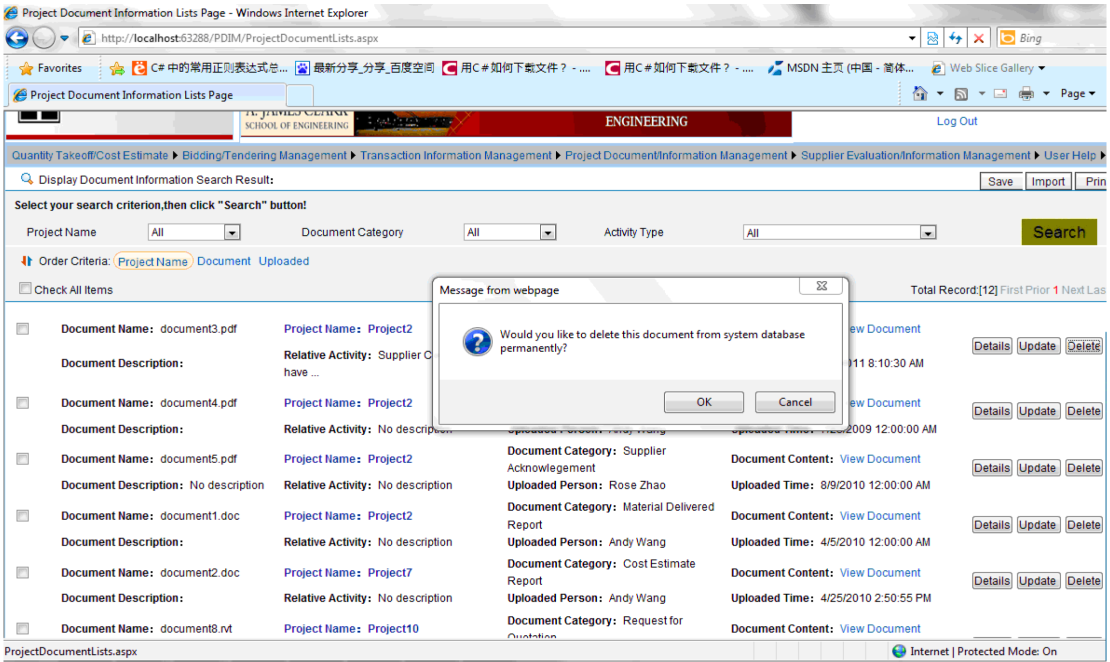


Figure 68 Alert to Delete One Specific Document Information

16) Alert to Save Project Document Information

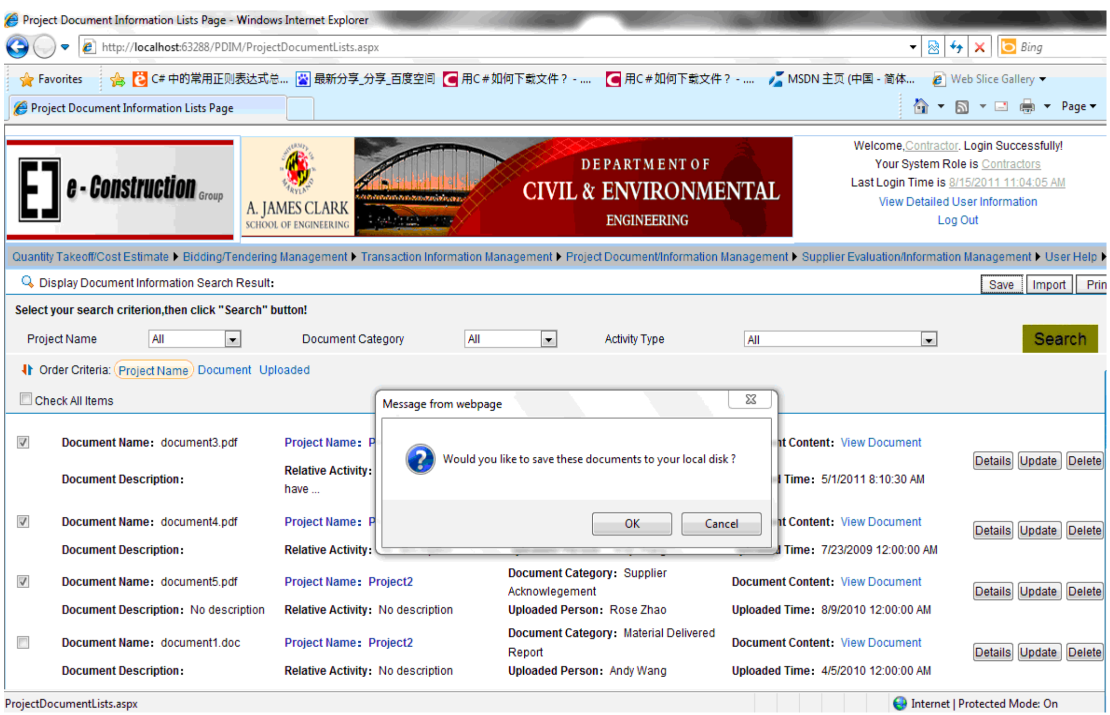


Figure 69 Alert to Save Project Document Information

17) Message of Saving Project Documents Successfully

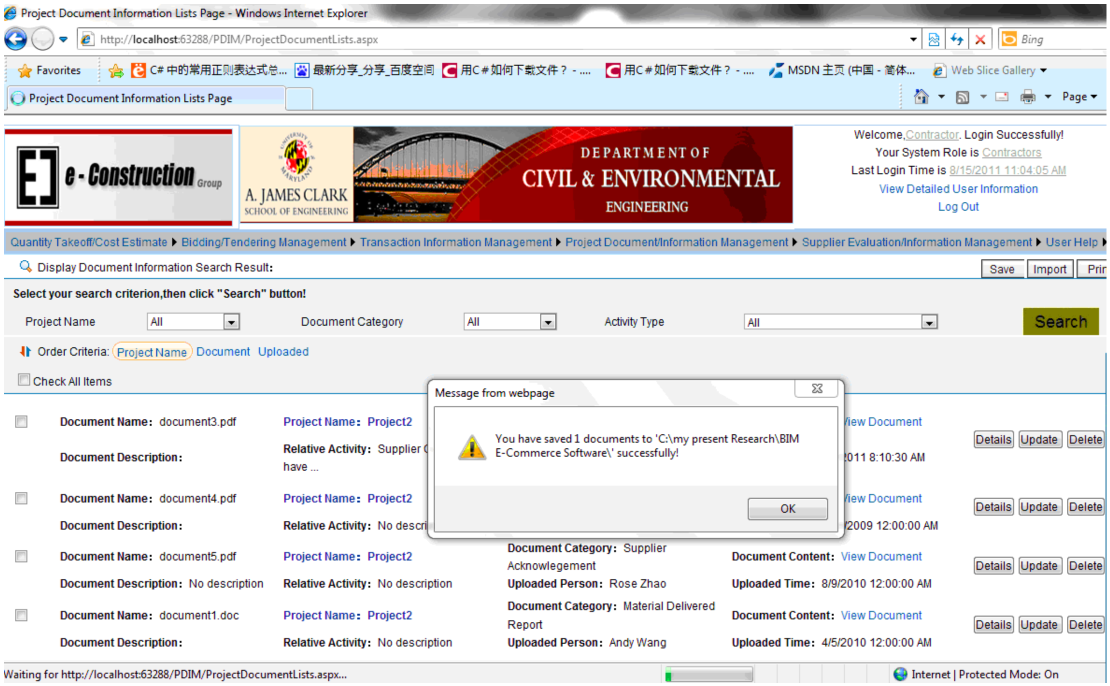


Figure 70 Message of Saving Project Documents Successfully

18) Inquire about Whether to Import Project Documents

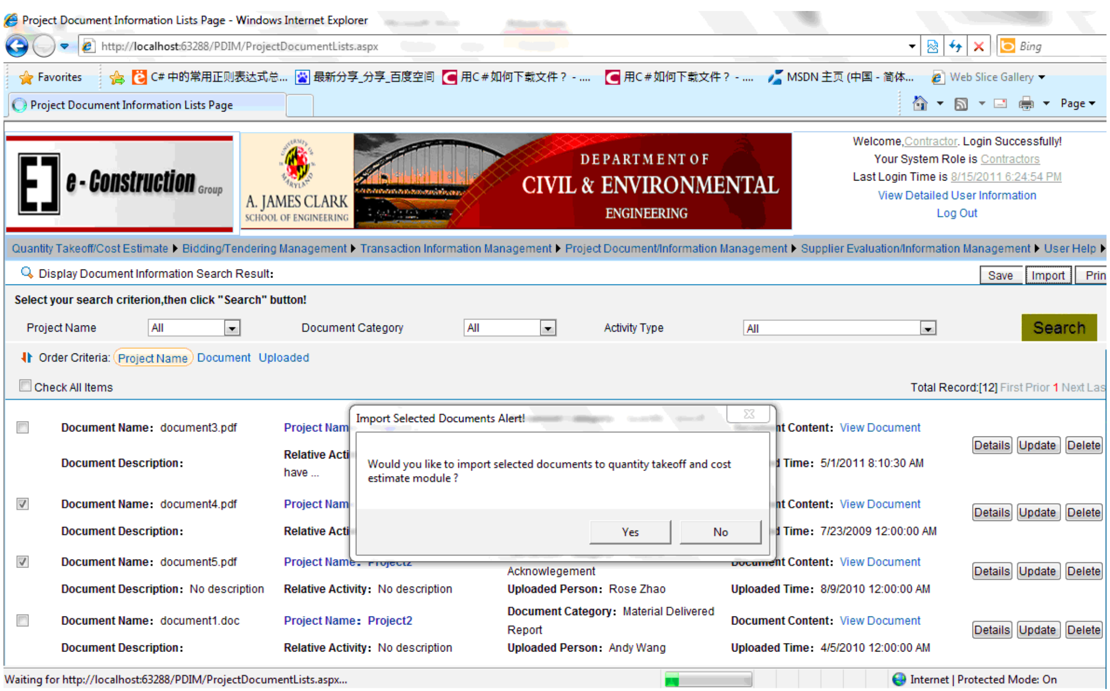


Figure 71 Inquire about Whether to Import Project Documents

19) Message of Importing Project Documents Successfully

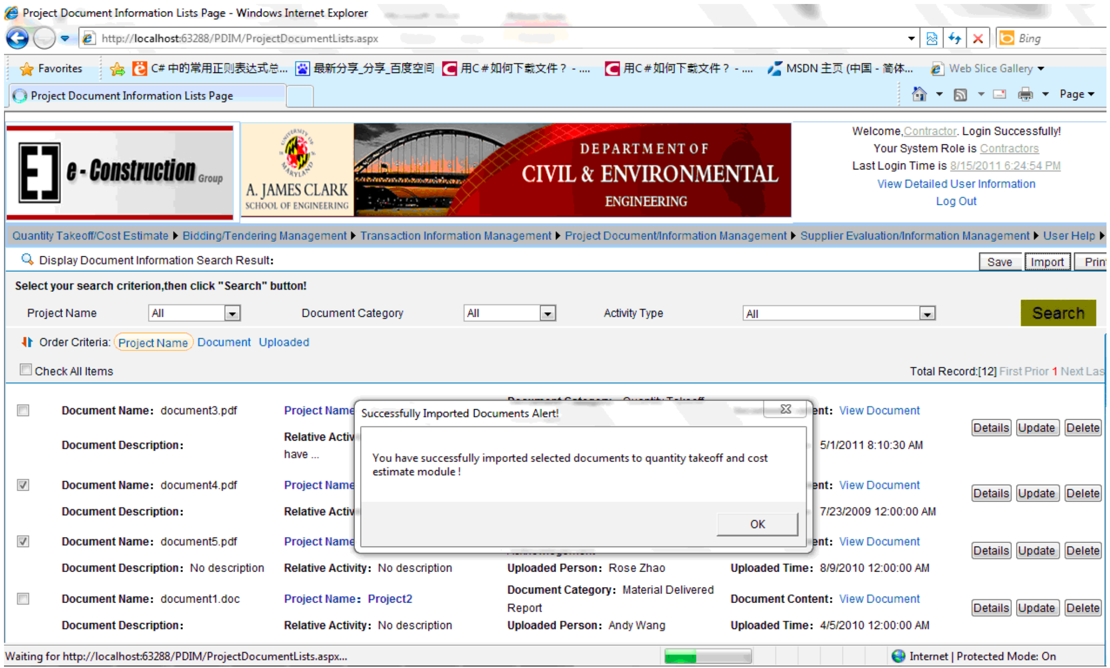


Figure 72 Message of Importing Project Documents Successfully

20) Print Document Information List Page

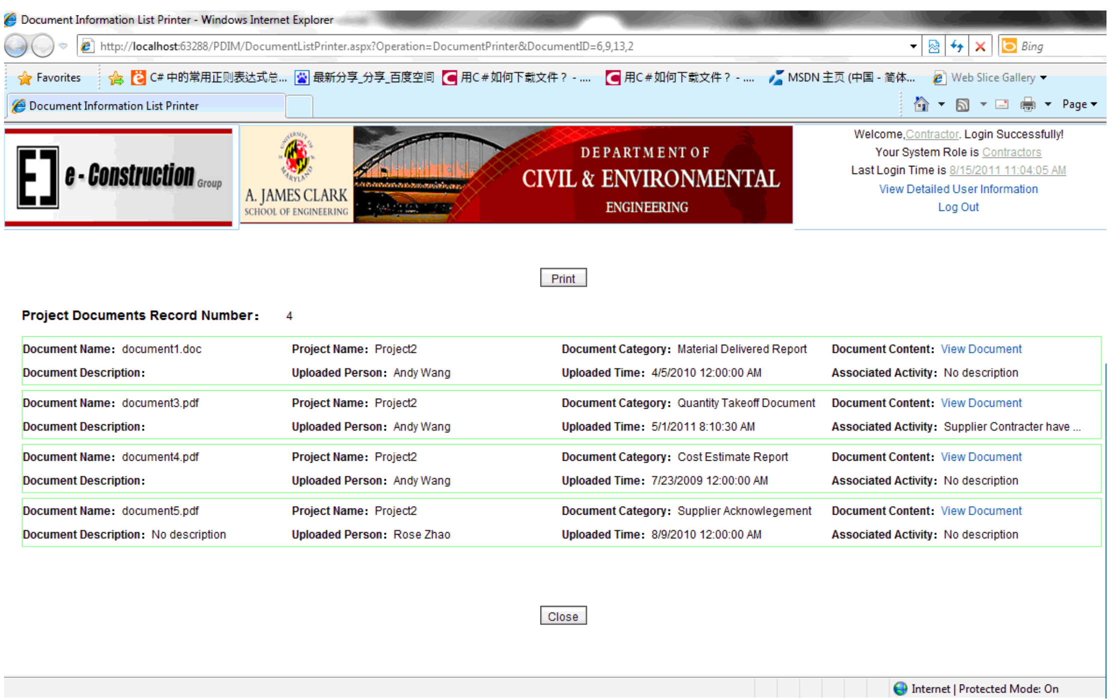


Figure 73 Print Document Information List Page

21) Detailed Document Information Page

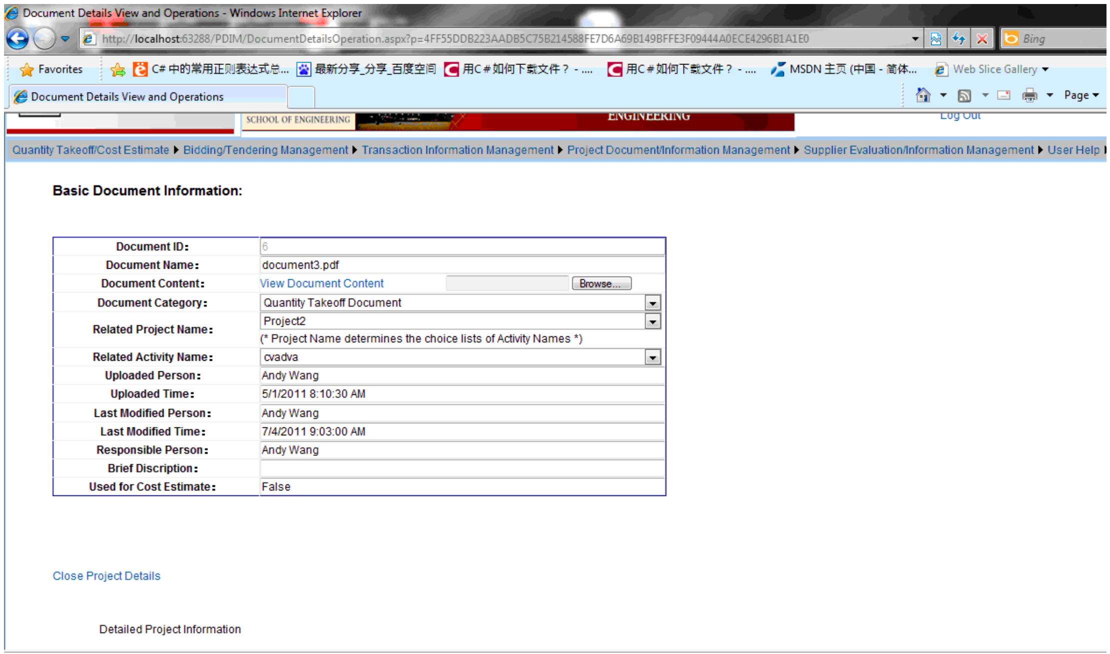


Figure 74 Detailed Documents Information Page

22) Document Related Detailed Project Information

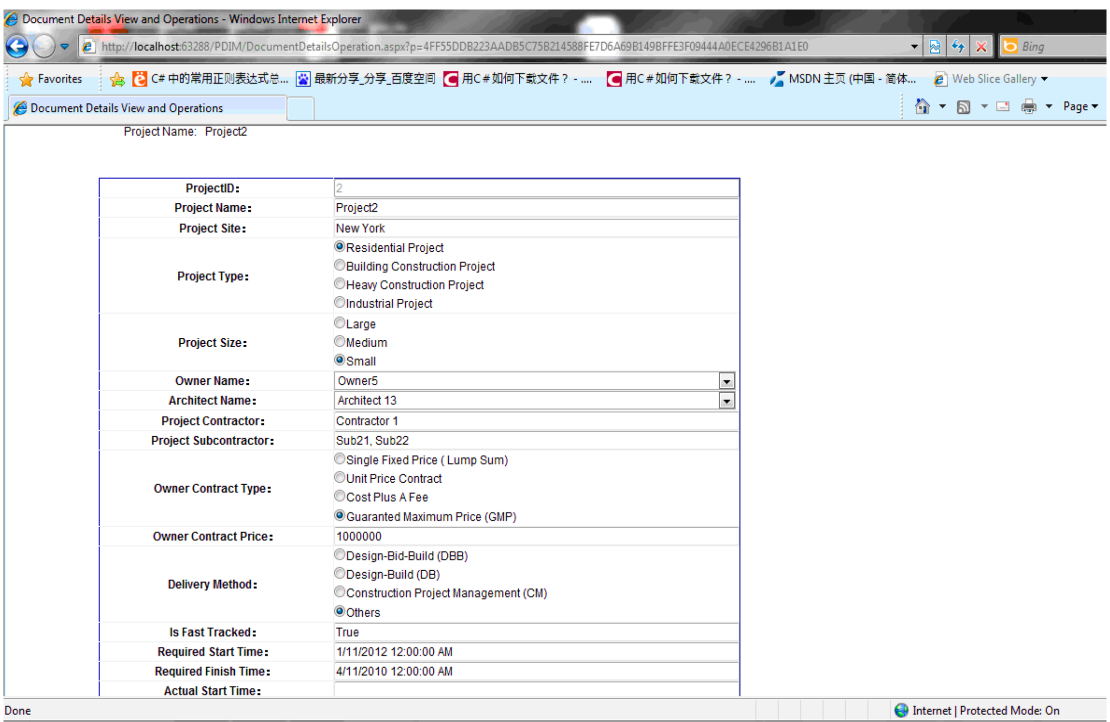


Figure 75 Documents Related Detailed Project Information

23) Document Related Detailed Activity Information

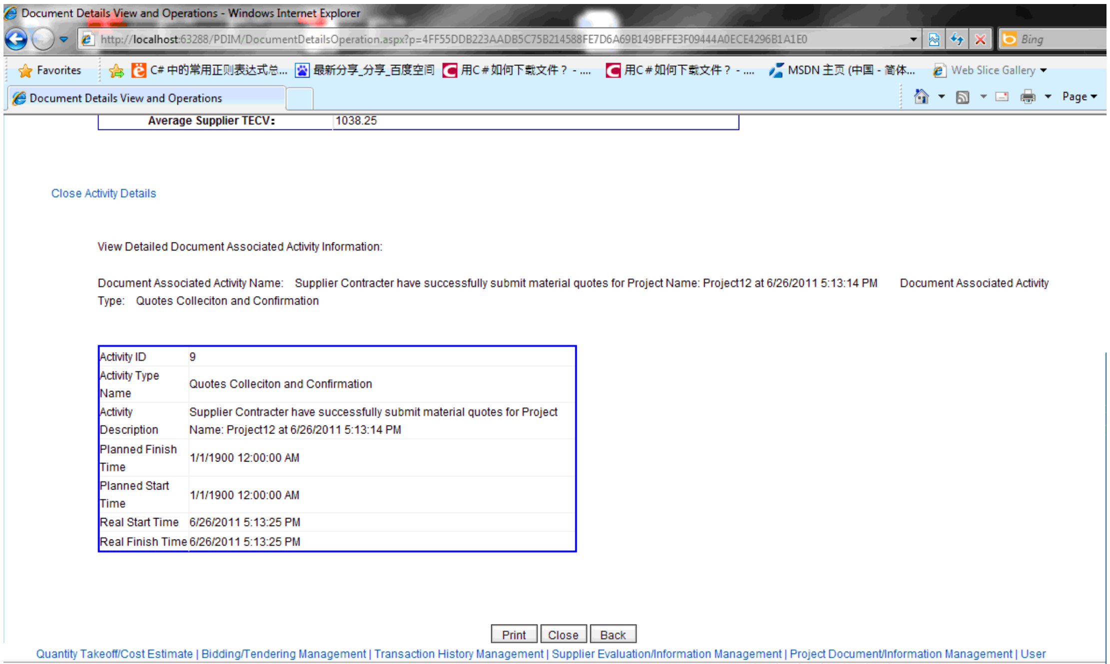


Figure 76 Documents Related Detailed Activity Information

24) Modify, Add Basic Document and Change Related Project / Activity Information

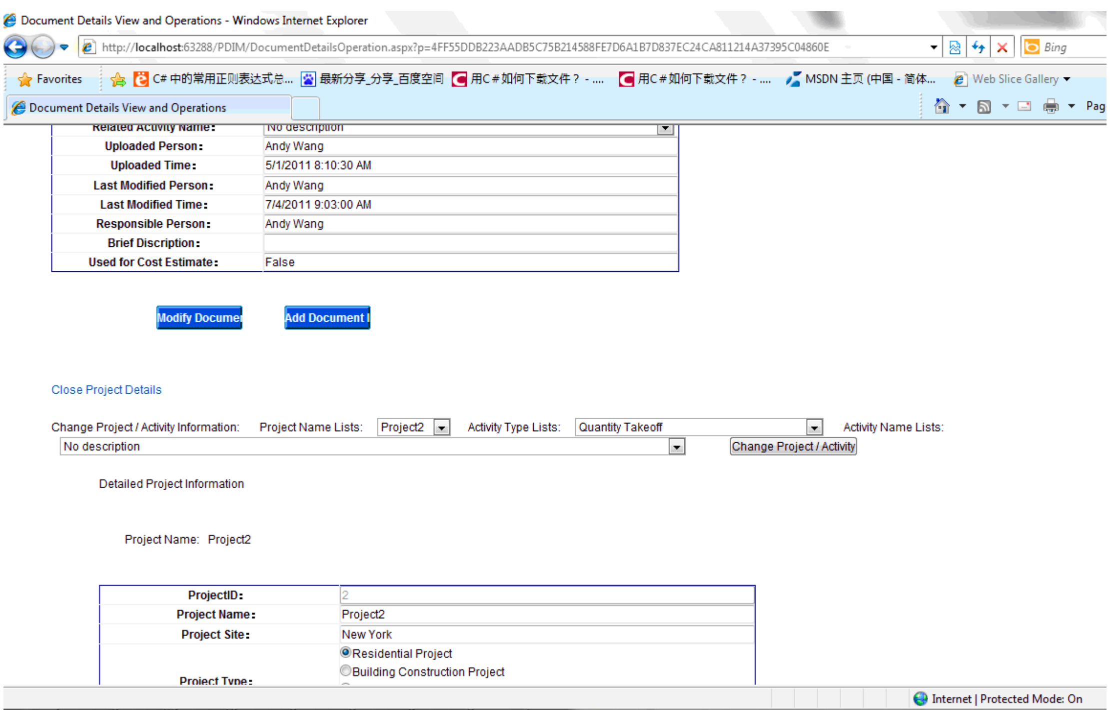


Figure 77 Modify, Add Basic Document and Change Related Project / Activity Information

25) Activity Information List Page

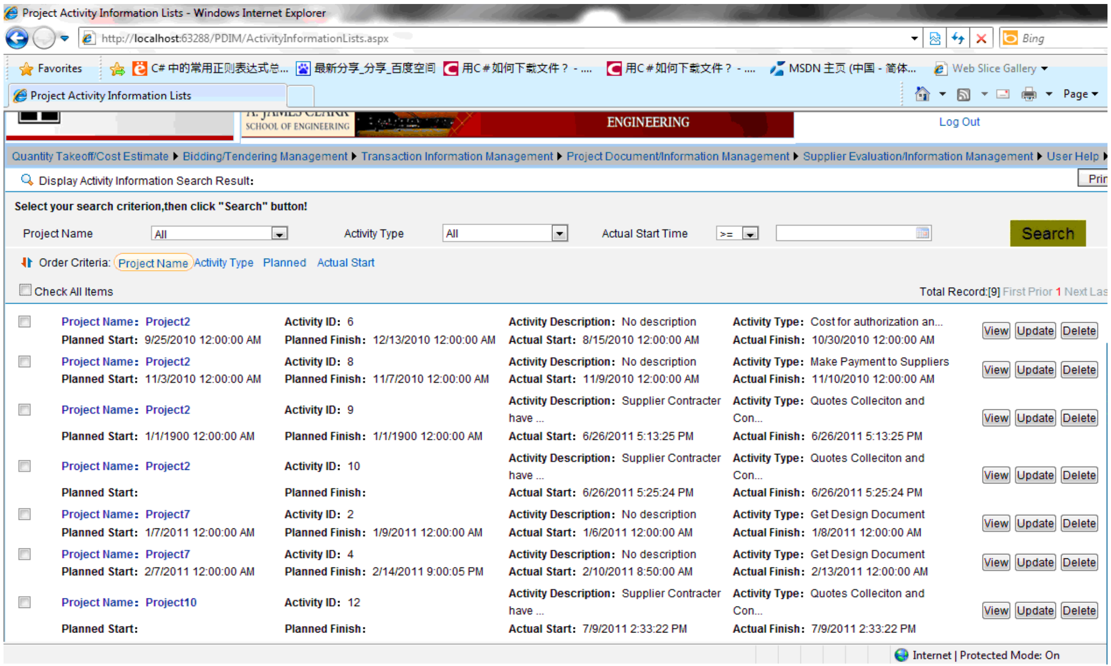


Figure 78 Activity Information List Page

26) Alert to View Detailed Activity Information

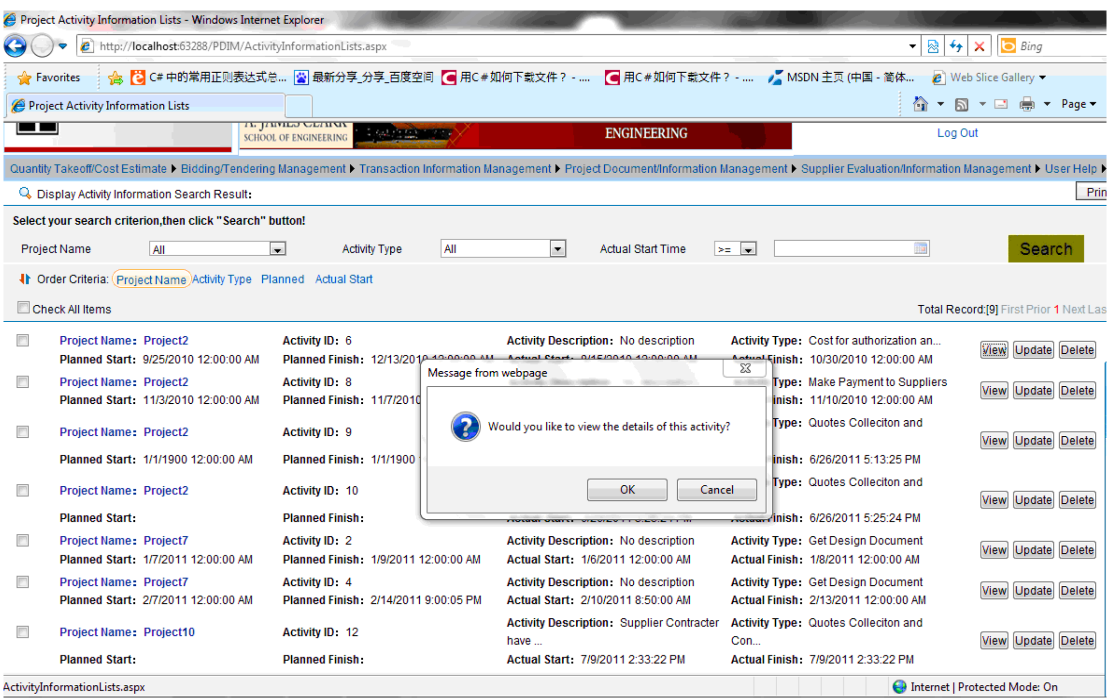


Figure 79 Alert to View Detailed Activity Information

27) Alert to Update Detailed Activity Information

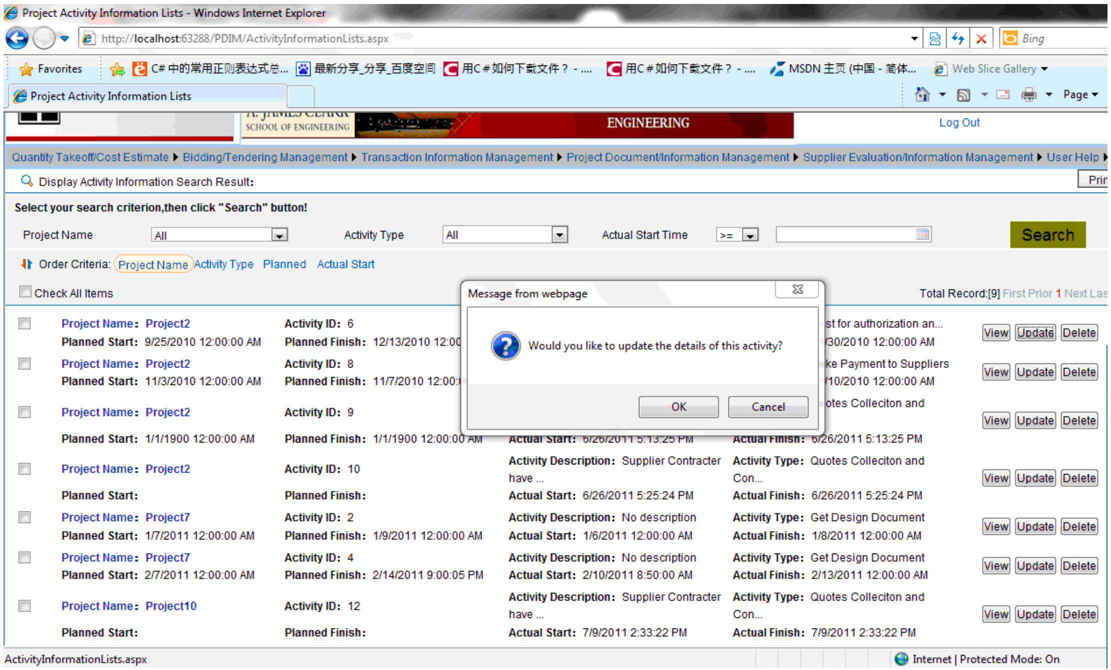


Figure 80 Alert to Update Detailed Activity Information

28) Alert to Delete One Activity Information

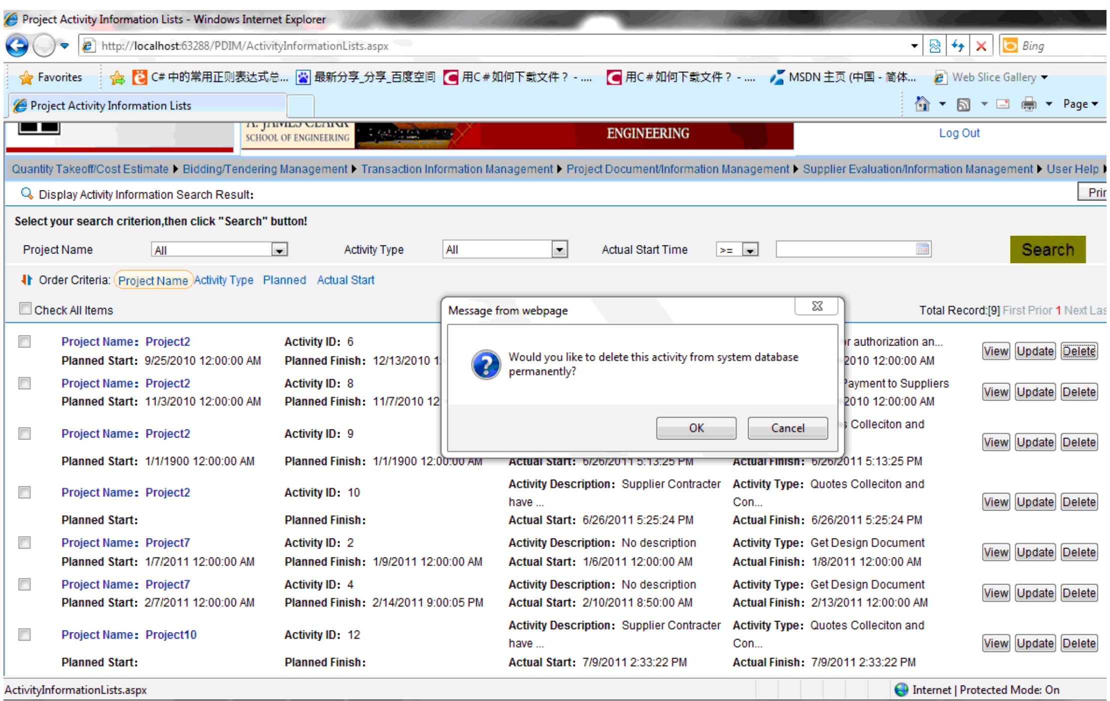


Figure 81 Alert to Delete One Activity Information

29) Print Activity Information List

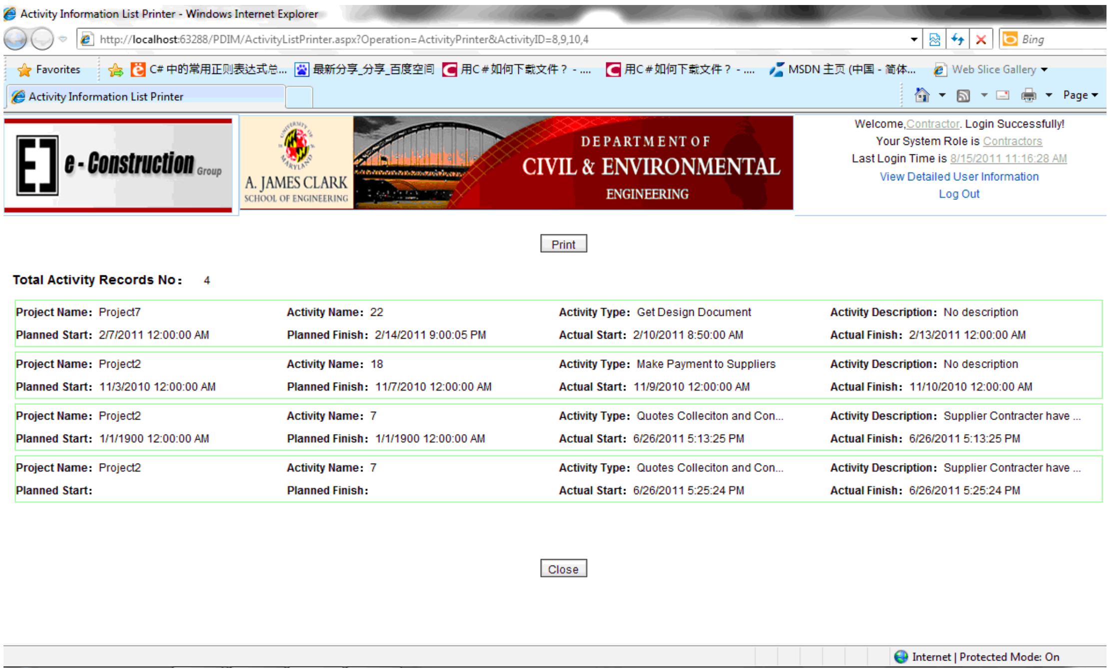


Figure 82 Print Activity Information List

30) View Detailed Activity Information

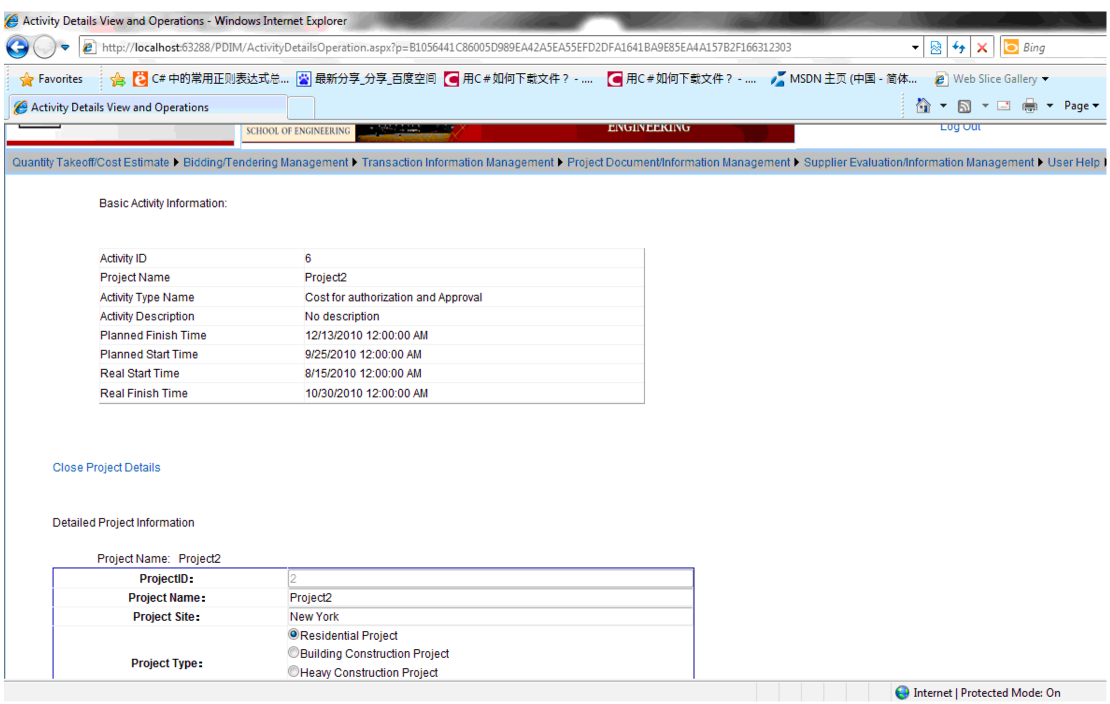


Figure 83 View Detailed Activity Information

31) View Detailed Activity Associated Project Information

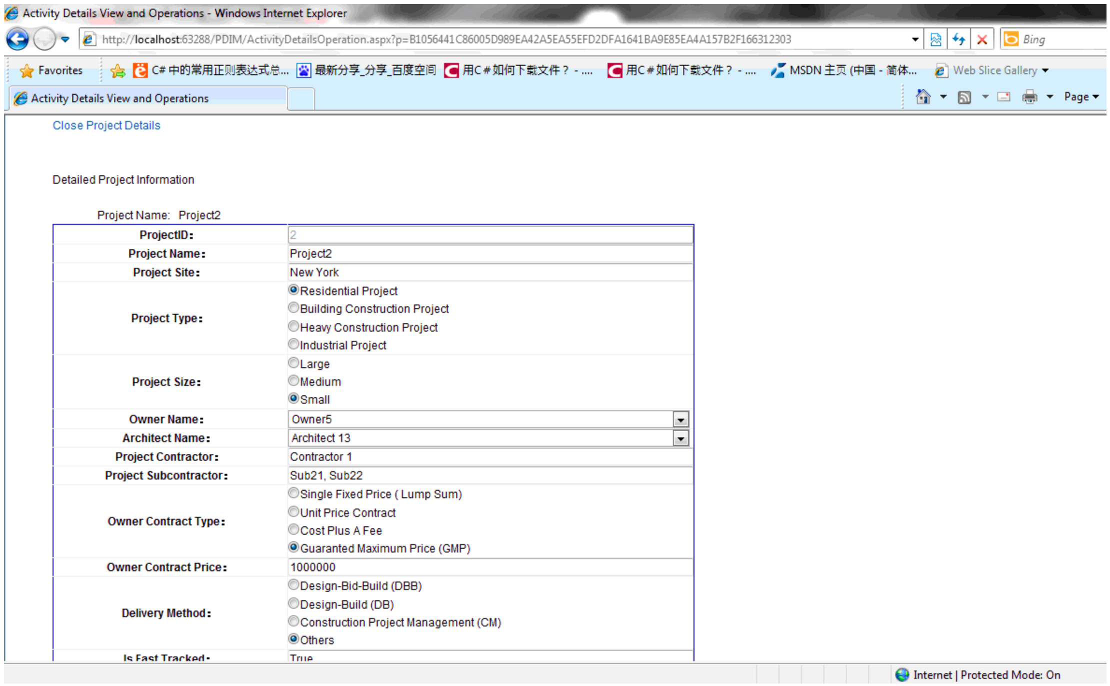


Figure 84 View Detailed Activity Associated Project Information

32) View Detailed Activity Associated Document Information

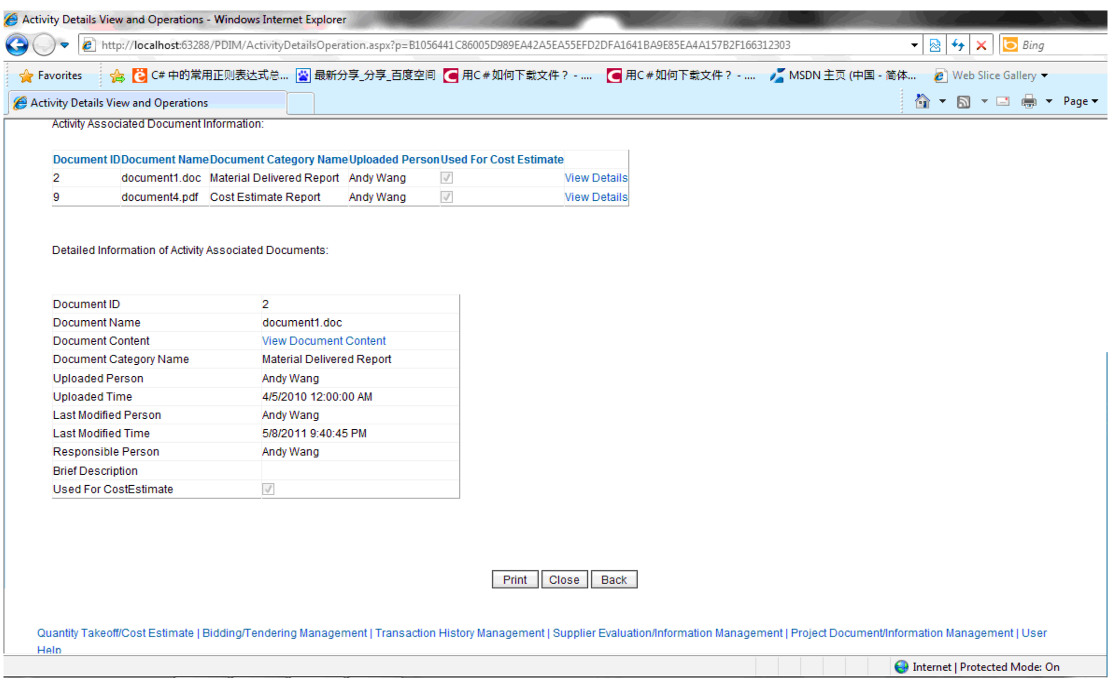


Figure 85 View Detailed Activity Associated Document Information

33) Edit, Add Activity Information and Change Related Project Information

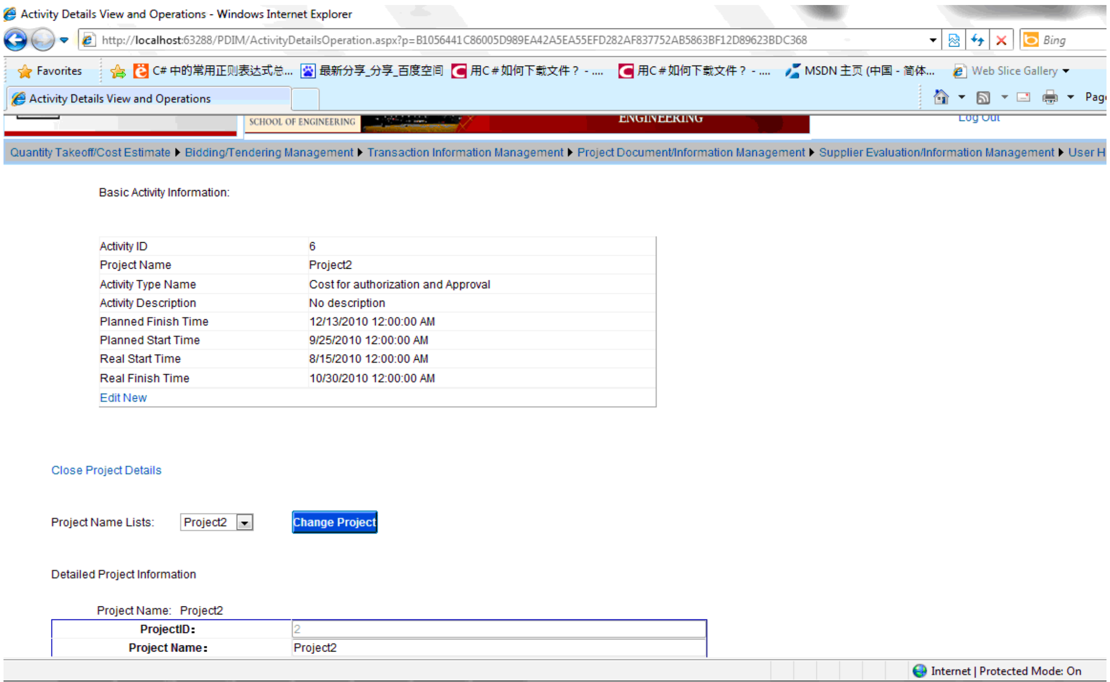


Figure 86 Edit, Add Activity Information and Change Related Project Information

34) Modify, Add Activity Related Supplier and Edit, Delete Project Information

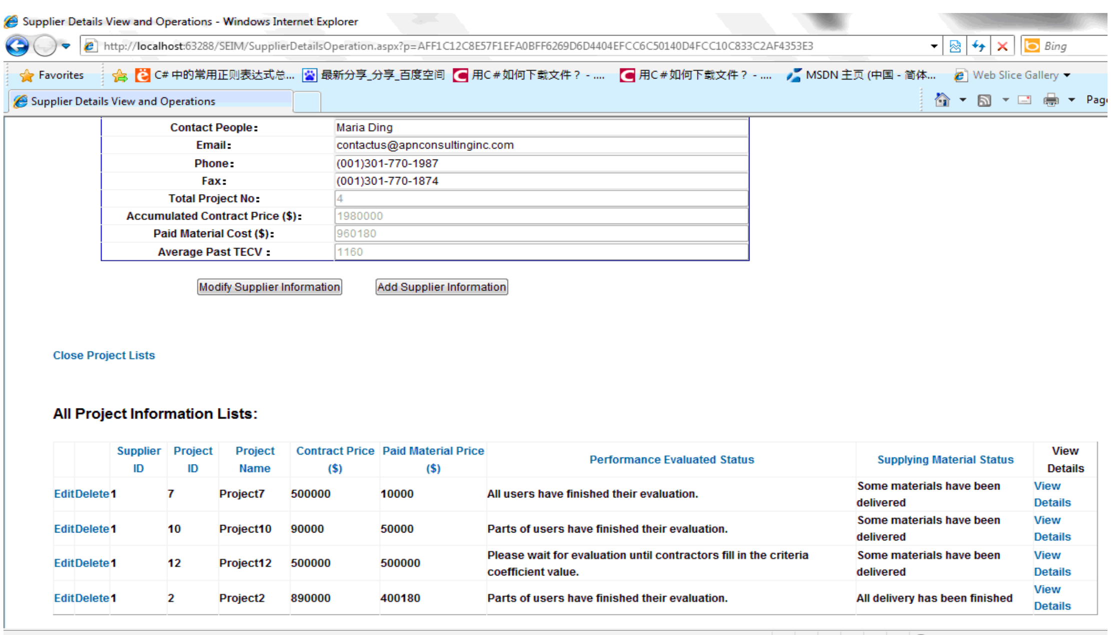


Figure 87 Modify, Add Activity Related Supplier Information and Edit, Delete Project Information

35) View Owner Information List and Specific Owner Information

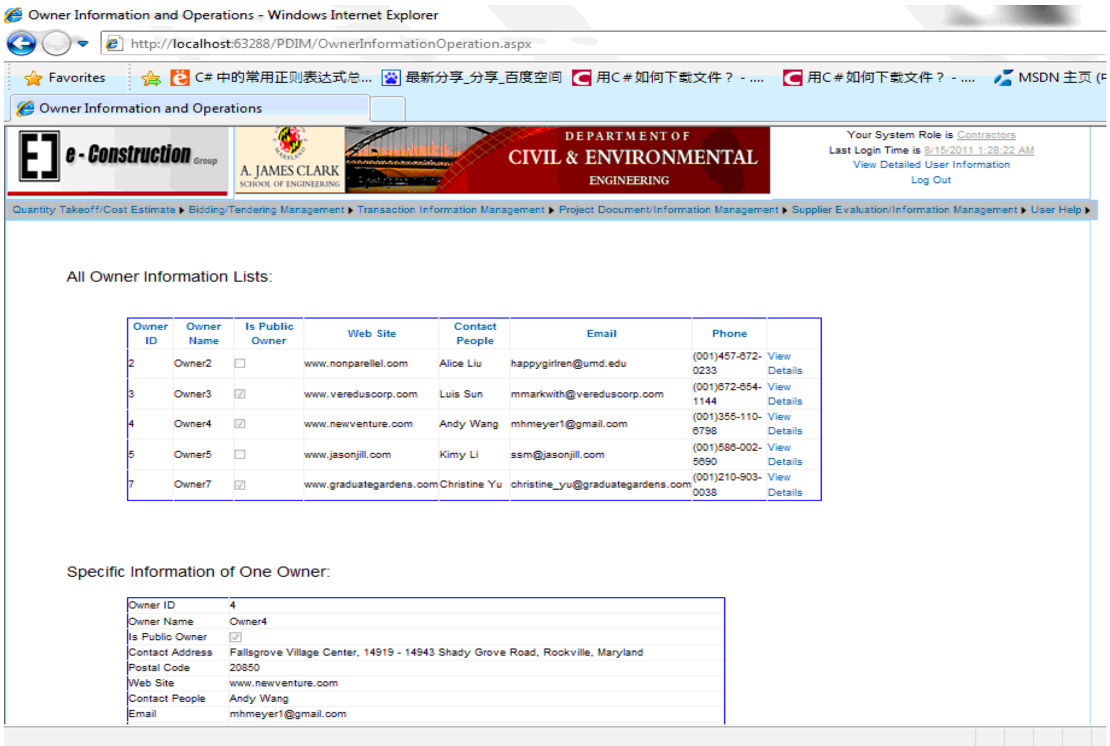


Figure 88 View Owner Information List and Specific Owner Information

36) View Architect Information List and Specific Architect Information

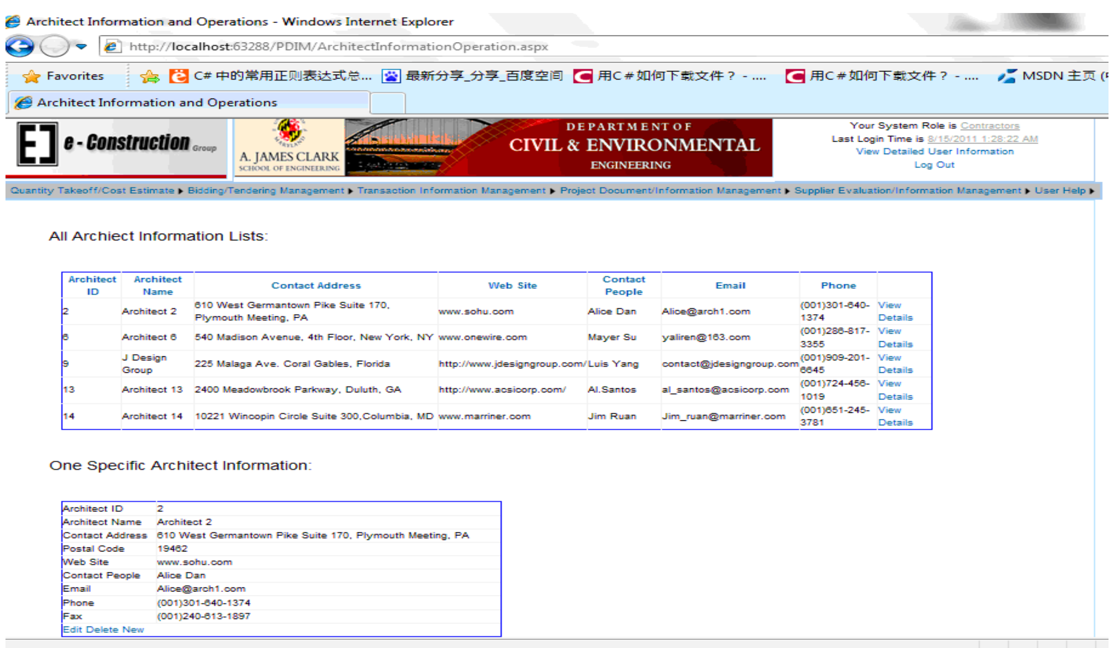


Figure 89 View Architect Information List and Specific Architect Information

Appendix 6. Supplier Performance Evaluation and Information Management Interface

1) View Supplier Information List Page

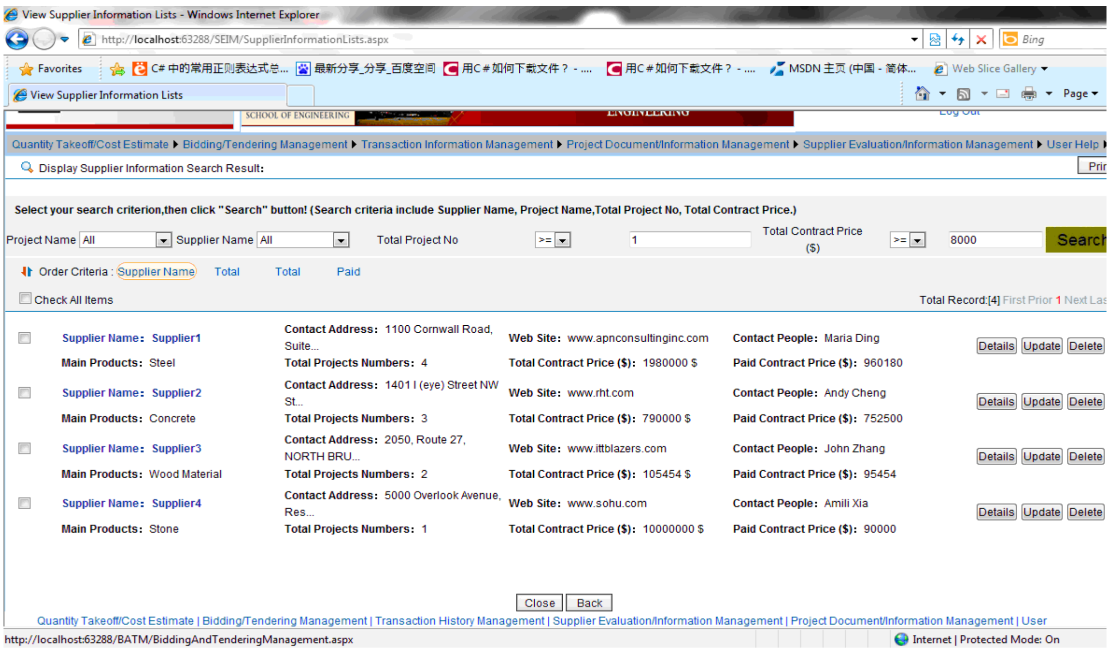


Figure 90 View Supplier Information List

2) Alert to View Detailed Supplier Information

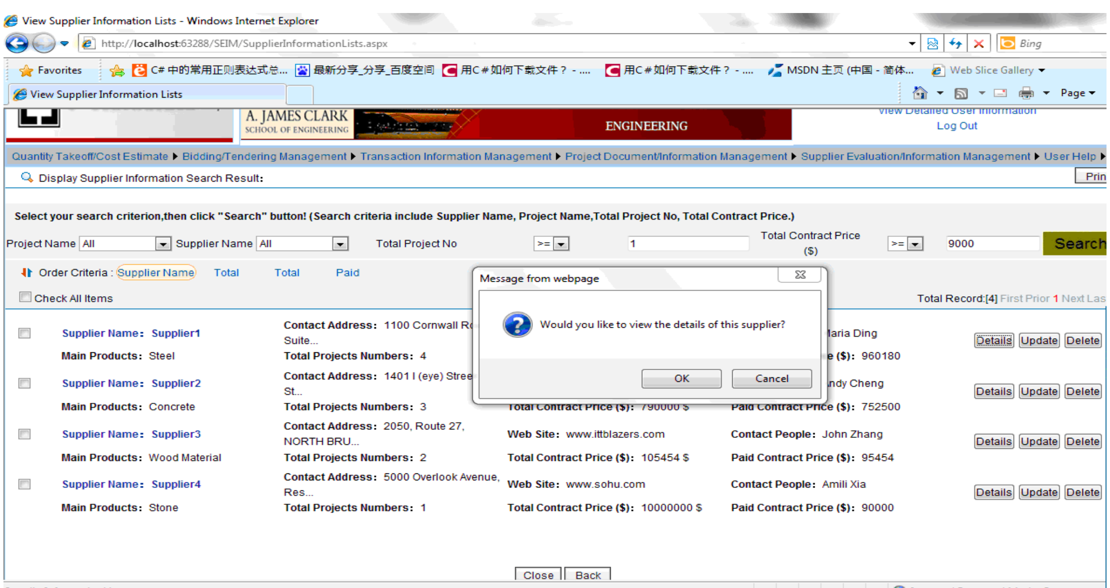


Figure 91 Alert to View Detailed Supplier Information

3) Alert to Update Detailed Supplier Information

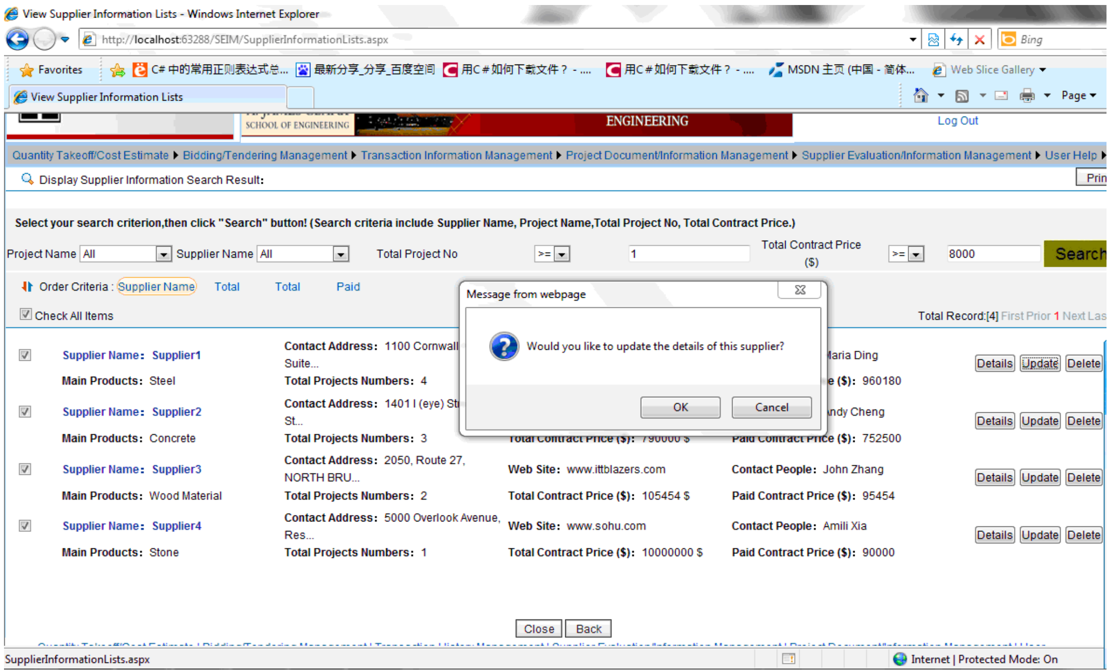


Figure 92 Alert to Update Detailed Supplier Information

4) Alert to Delete One Supplier Information

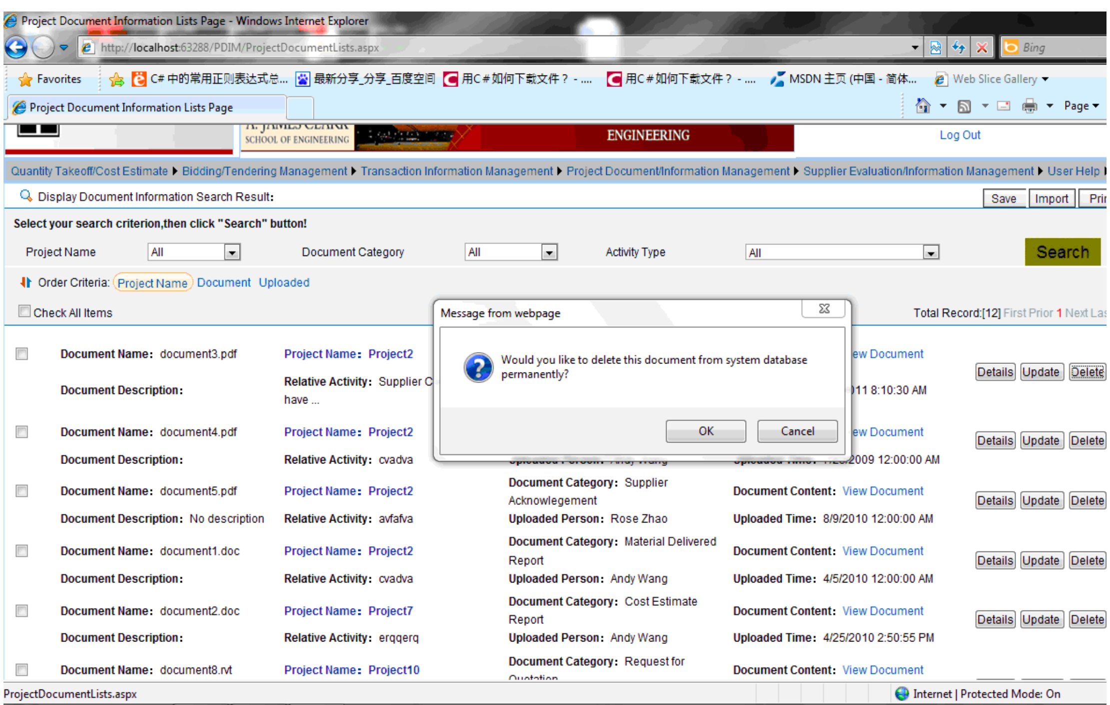


Figure 93 Alert to Delete One Supplier Information

5) Print Information List of Selected Suppliers

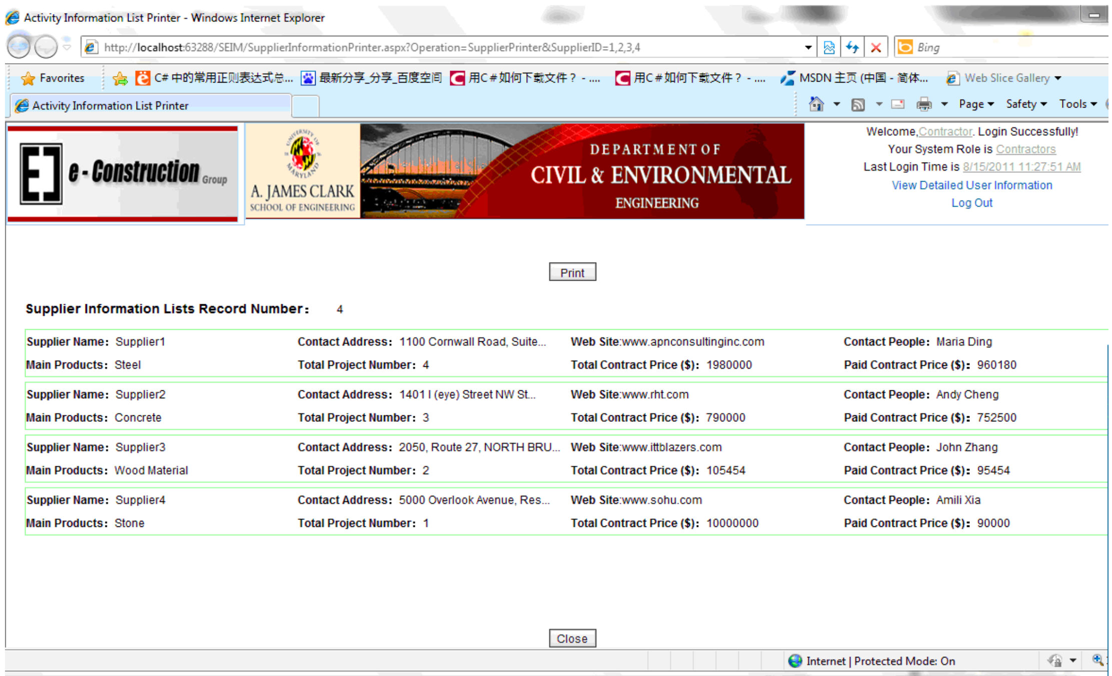


Figure 94 Print Information List of Selected Suppliers

6) View Detailed Specific Information of One Supplier

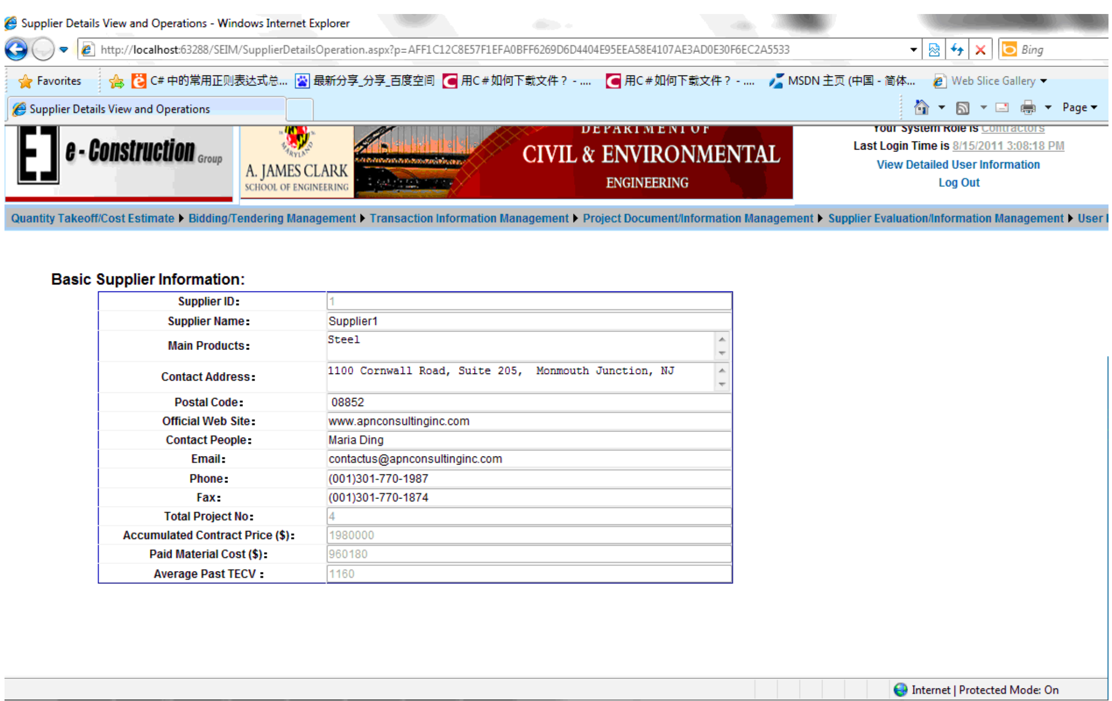


Figure 95 View Detailed Specific Information of One Supplier

7) View Detailed Specific Supplier Related Project Information

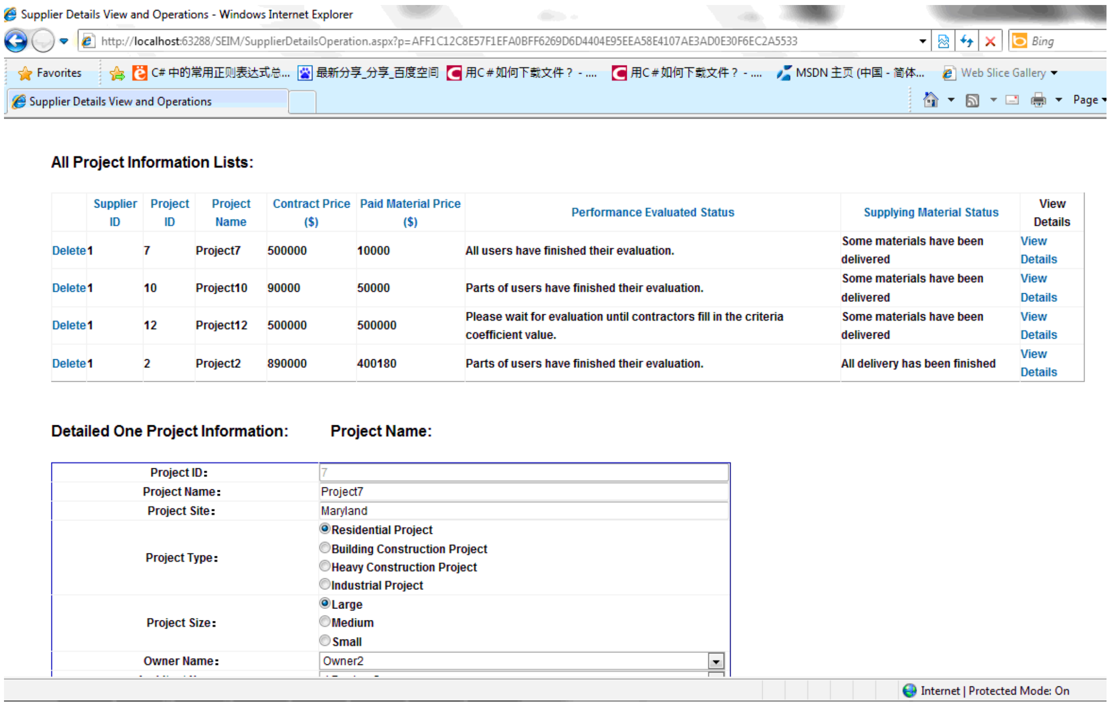


Figure 96 View Detailed Specific Supplier Related Project Information

8) View Detailed Supplier Related Contract Document Information

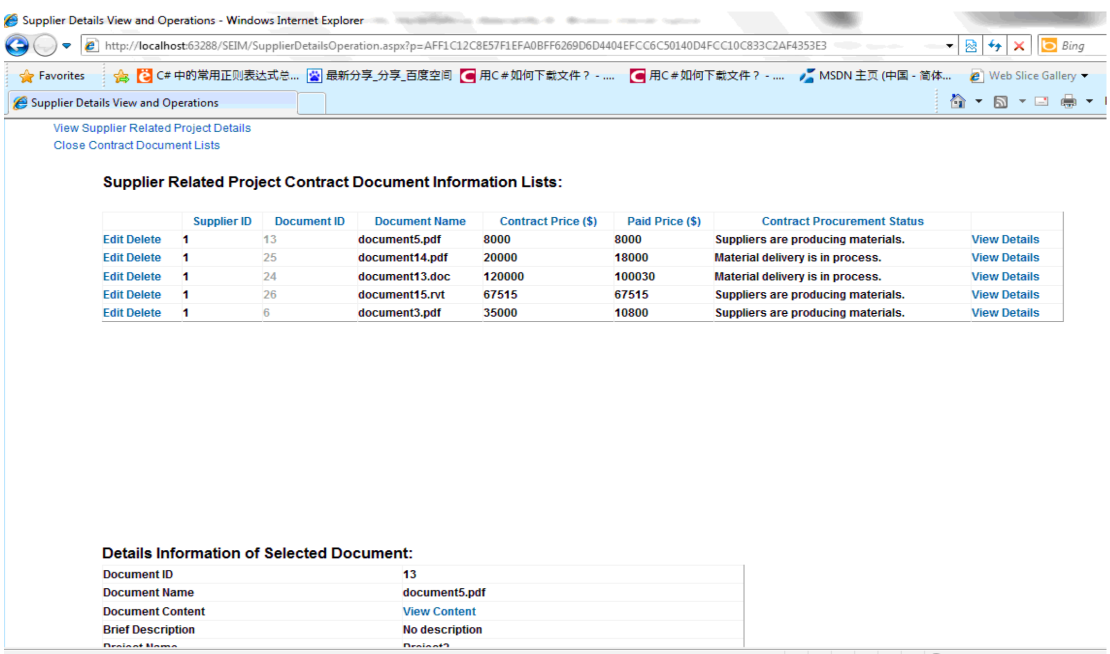


Figure 97 View Detailed Supplier Related Contract Document Information

9) Modify, Add Supplier Information, and Edit, Delete Supplier Related Project Information

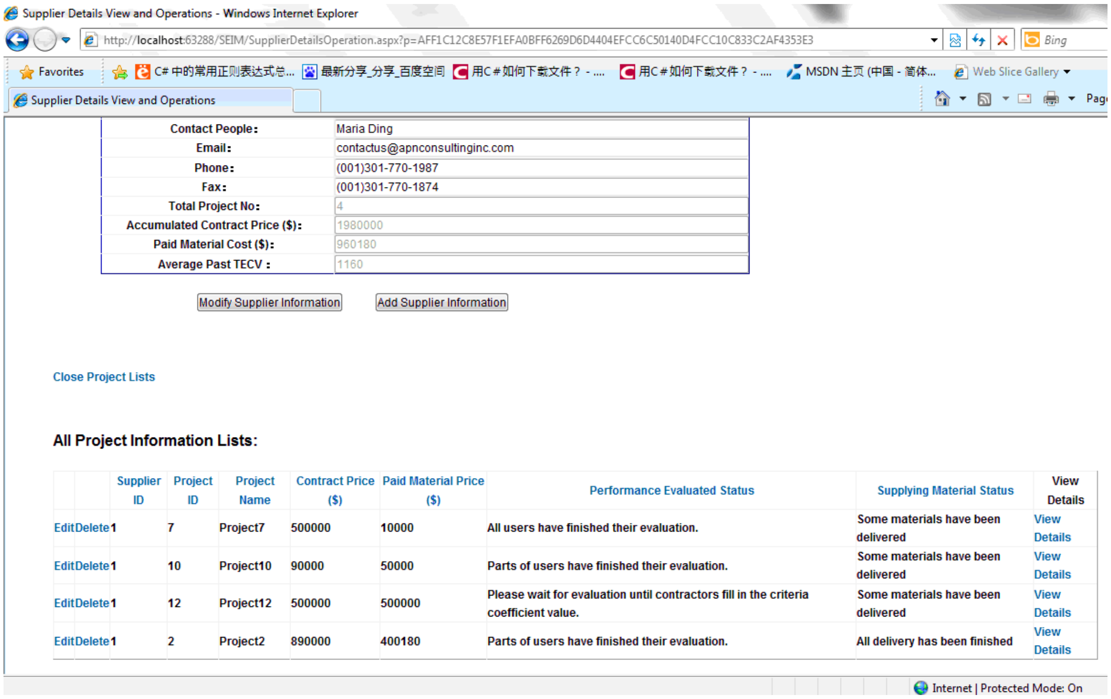


Figure 98 Modify, Add Supplier Information, Edit or Delete Supplier Related Project Information

10) Edit or Delete Supplier Related Contract Document Information

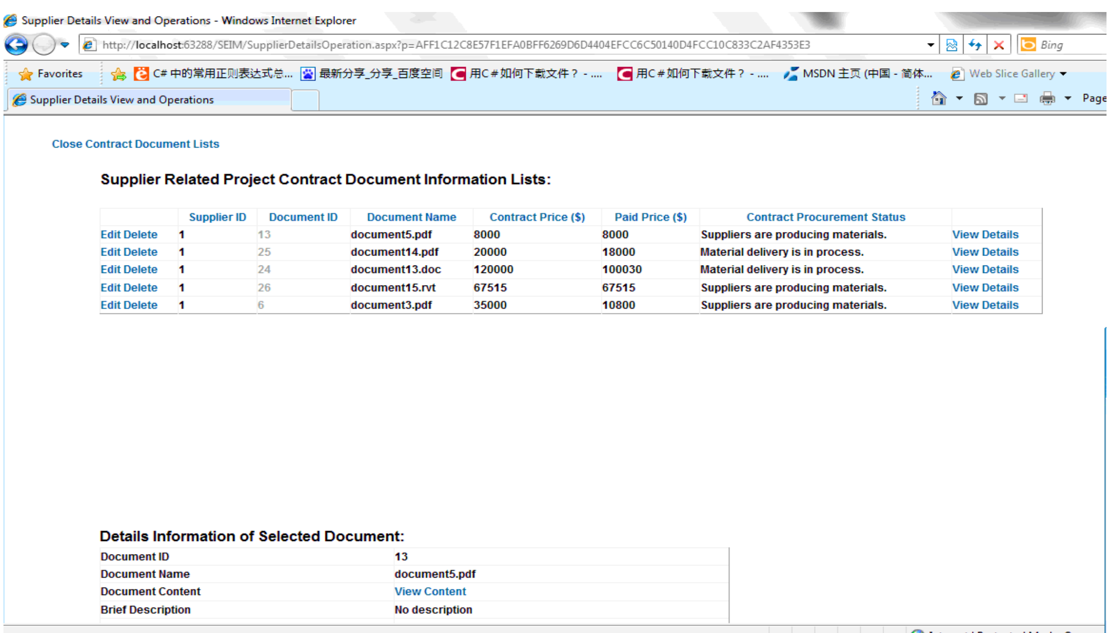


Figure 99 Edit or Delete Supplier Related Contract Document Information

11) Delete a Supplier from Performance Compare of Multiple Suppliers in a Project

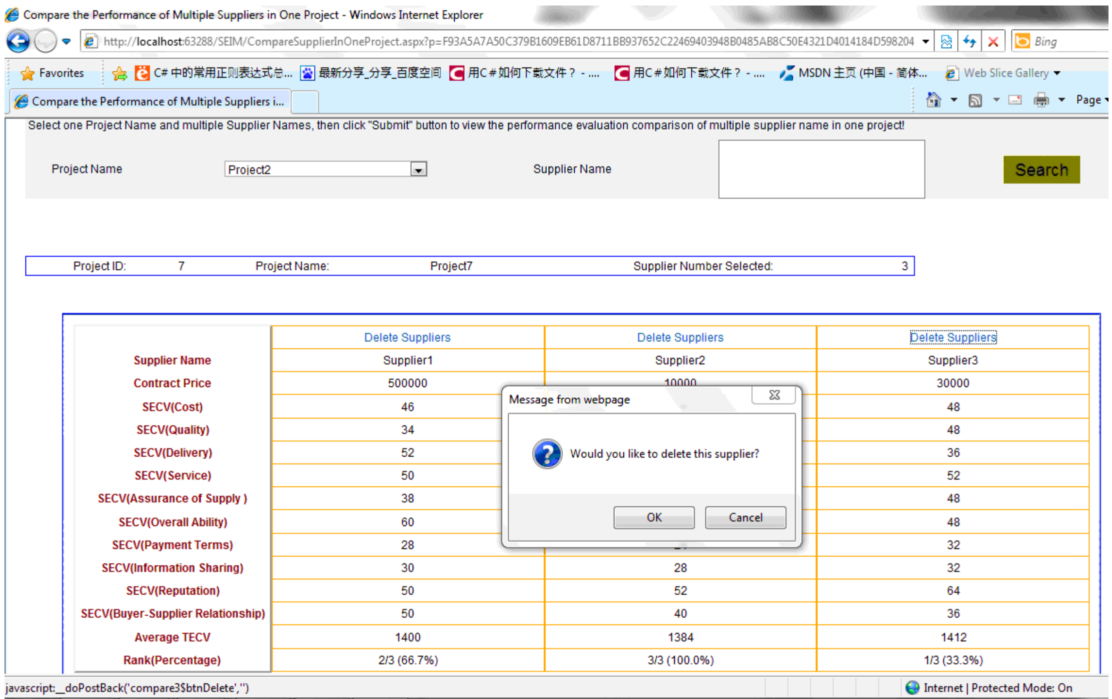


Figure 100 Delete a Supplier from Performance Compare of Multiple Suppliers in a Project

12) Delete a Project from Performance Compare of a Supplier in Multiple Projects

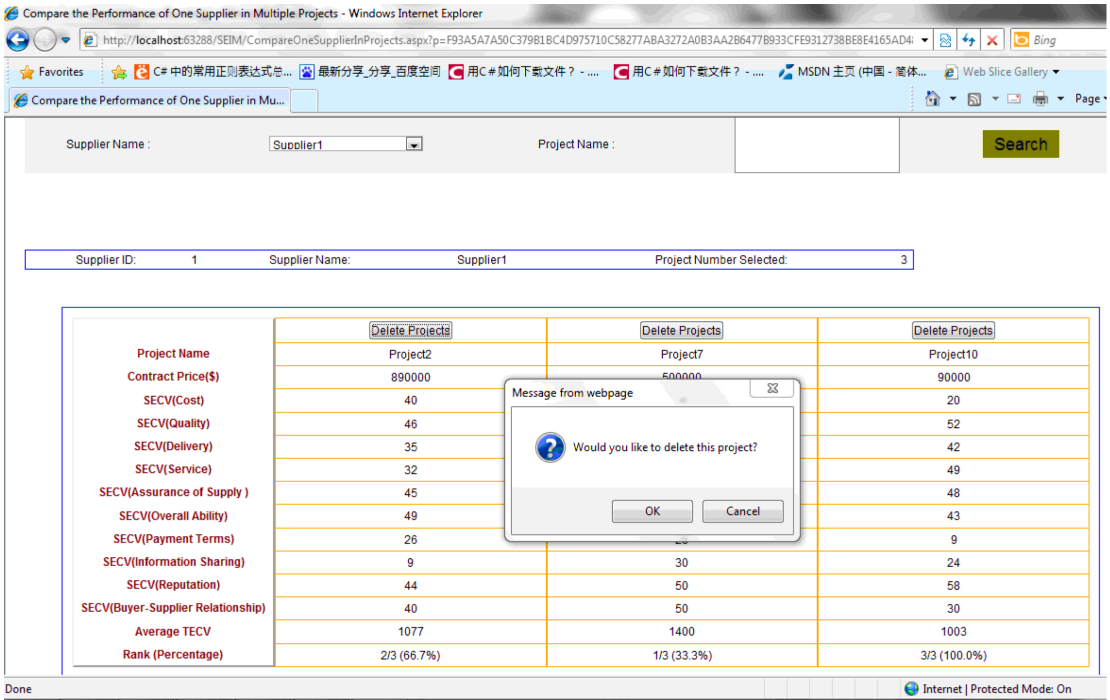


Figure 101 Delete a Project from Performance Compare of a Supplier in Multiple Projects

Appendix 7. Software Introduction and User Help Interface

1) Software Introduction Page

Figure 102 Software Introduction Page

2) User Help Page

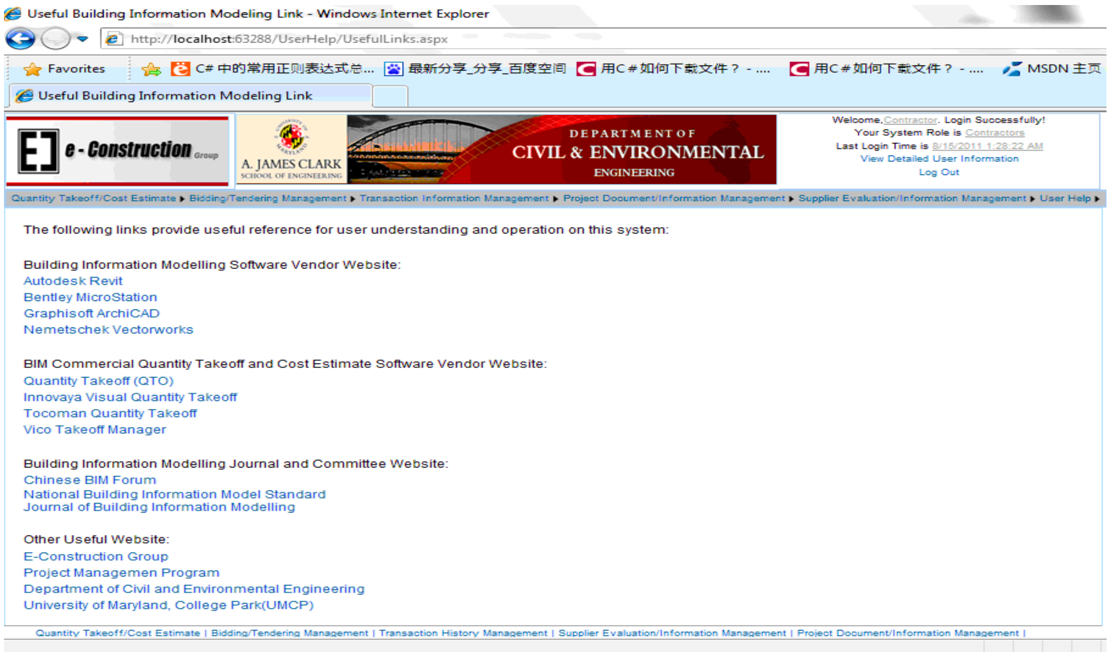


Figure 103 User Help Page

Appendix 8. Other Operation Interface

1) System User Login Help Page

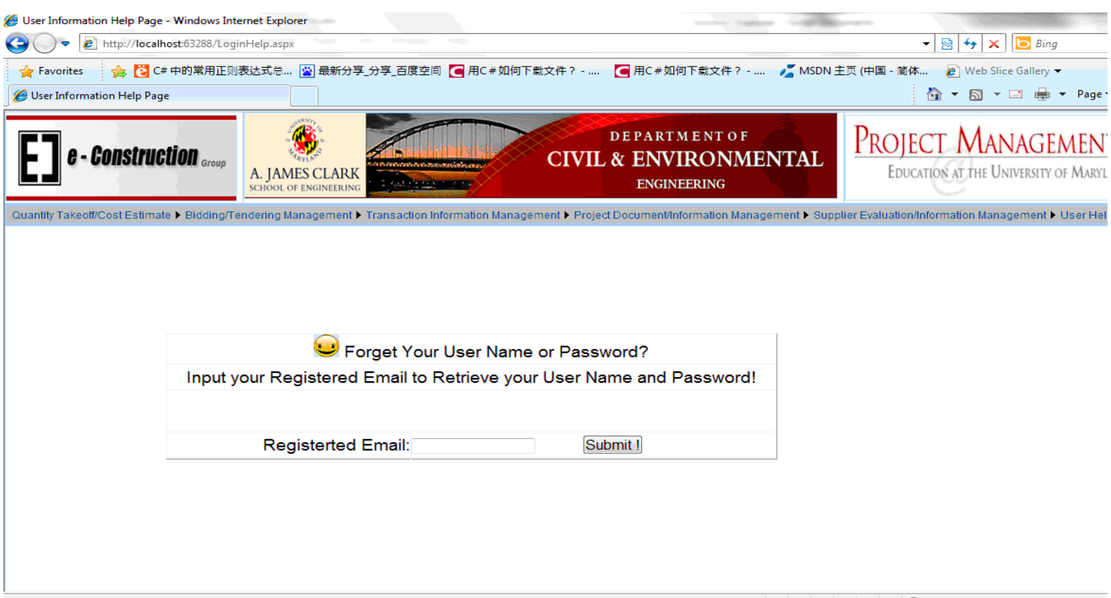


Figure 104 System User Login Help Page

2) Detailed System User Information and Role Information

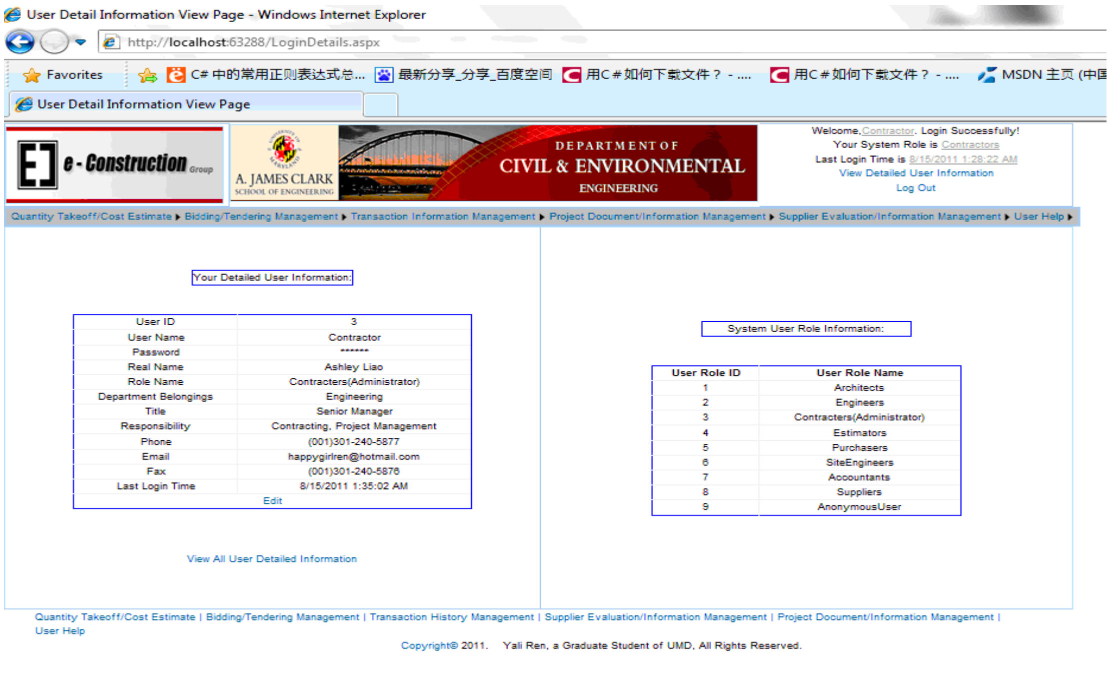


Figure 105 Detailed System User Information and Role Information

3) Operation of All System User Information

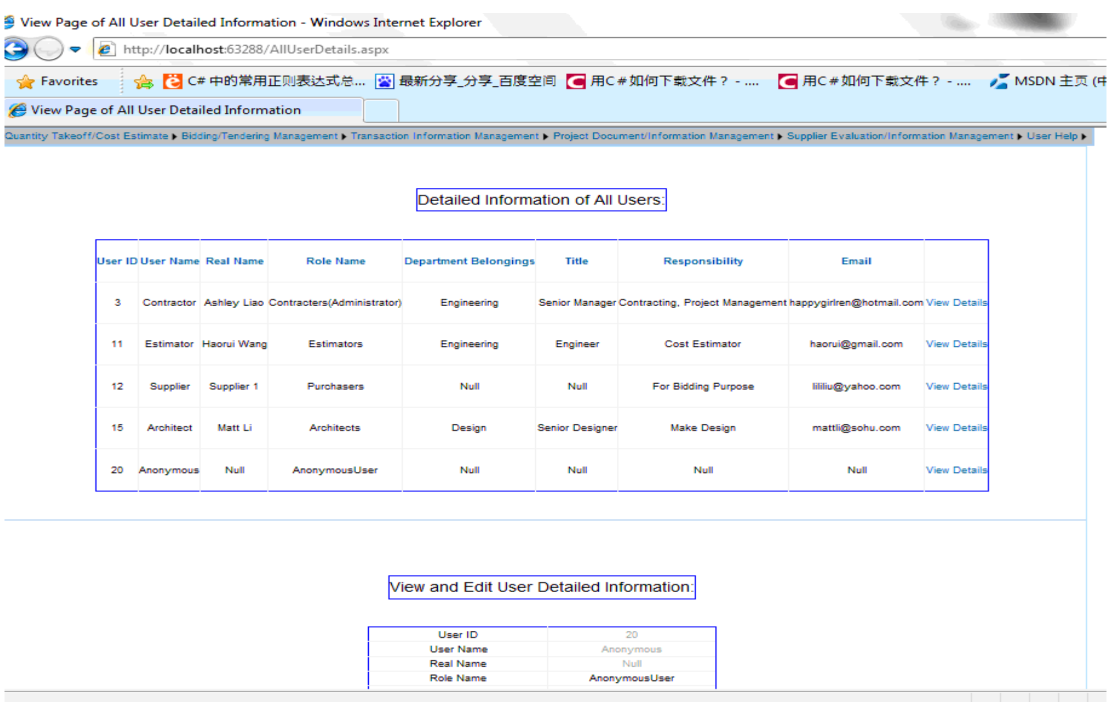


Figure 106 Operation of All System User Information

4) System Error Page

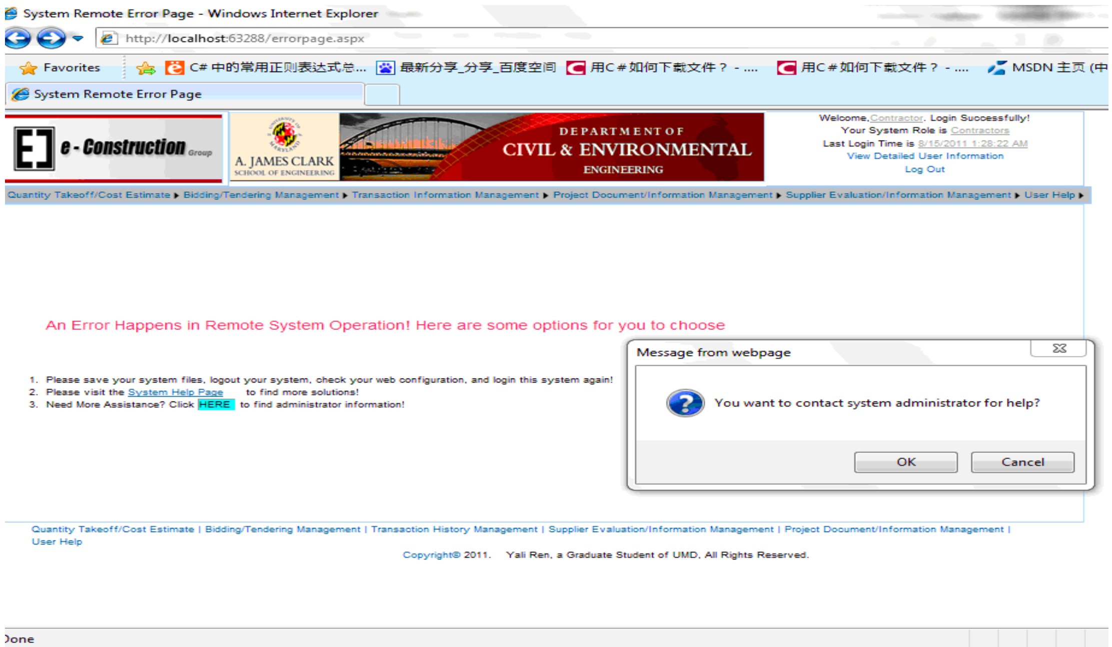


Figure 107 System Error Page

5) Page to Show System Administrator Information

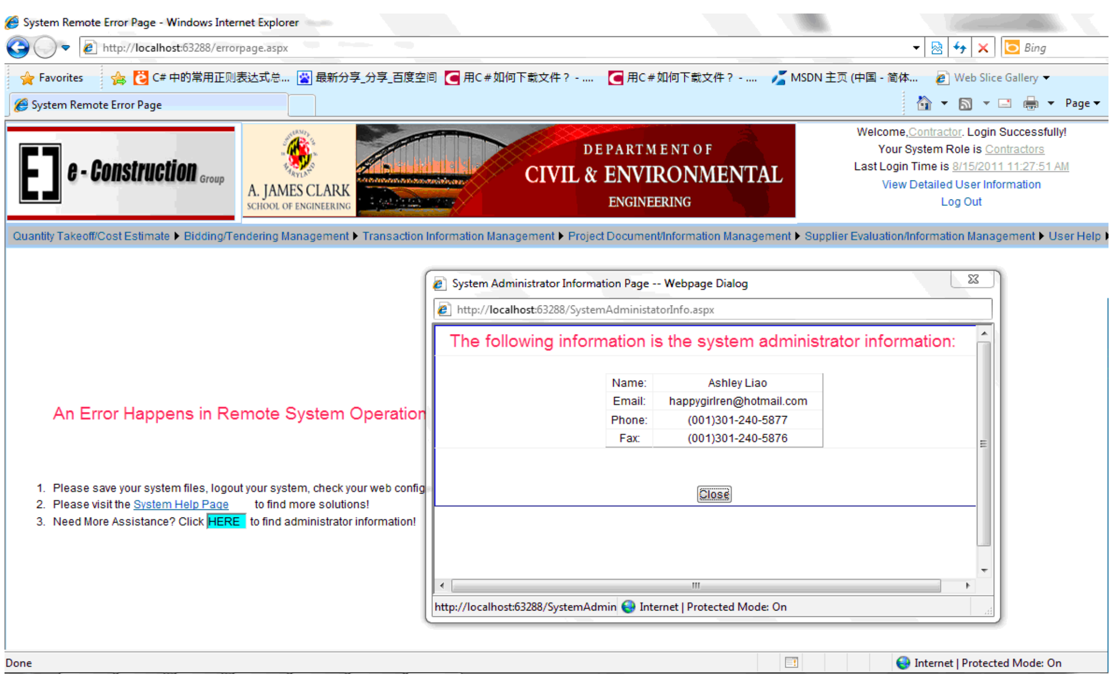


Figure 108 Page to Show System Administrator Information

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