FRAMEWORK FOR INTEGRATION OF BIM AND RFID IN STEEL CONSTRUCTION

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
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To my parent Yongling Shi and Shuzhen Lei, my wife Haiyan Xie,
my son Owen Shi and daughter Catherine Xie Shi

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The construction industry faces the challenge of synthesizing information and deriving insight from massive, dynamic, ambiguous and possibly conflicting digital data. A variety of data models and algorithms have been proposed and implemented to examine data, acquire information, and derive understanding from the information. Those models, systems, and implementations usually focus on one or several aspects of the design, procurement, construction, and maintenance phases of a project.

Construction professionals often face situations where they have to select or combine the best options to improve the accuracy and certainty of the decision-making process. Building Information Modeling (BIM) is a combination of all the project data, displayed in a designed systematic model. Examples of those systems include interactive design systems, decision support systems, expert systems, knowledge-based systems, virtual reality and 3D simulations.

There are high requirements to the steel iron worker personal skills for steel connections, which limits the innovation of steel erection methods and management. Project manager needs to make decisions on the arrangement of subcontractor work sequences, project control, safety, and quality.

The focus of this research is to investigate and develop the framework of using Radio Frequency Identification (RFID) and BIM for the decision-making process in steel construction. It aims to maximize functions software and hardware and to improve compatibility of those software and database used in construction projects by using BIM/RFID system.

In this research, Building Information Modeling (BIM) and RFID deal with structural steel fabrication and erection to develop a portable RFID database which can assist steel fabrication and erection efficiency and accuracy. RFID and BIM integration with Manufacturing Systems Integration (MSI) make a framework for helping users in making decisions when dealing with numerous fabrication and erection job conditions.

The significance of the proposal framework is in helping user to select a optimal plan for fabrication, delivery and erection; enabling data stakeholders to detect the expected information and discover the unexpected situations in massive data sets; developing a BIM zoning plan for jobsite safety control; and describing a RFID and GPS future position system.

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CHAPTER 1
INTRODUCTION

Motivation

Over the past decade advanced uses of information technology (IT) in construction have become more commonly accepted by most construction firms. The implementations of information technology (IT) in construction management have undergone rapid developments. These implementations have related to a multitude of hardware, software, and networks with the functions of storing, transferring, processing and presenting information. General technologies, such as semantic modeling, data mining, mobile technologies, or domain-oriented ones, i.e. e-commerce, collaborative websites, or digital mock-ups, have revealed a great spectrum of potential in the construction industry. Information technology helps in the sharing of information and in advancing collaboration among project teams. The implementation of IT in the construction industry can be used in many situations. For example, projects are being designed and managed by teams located in different countries; design or engineering is being outsourced and completed in collaborative fashion; cameras and sensors are used to continuously monitor in real-time the state of infrastructures and buildings.

The majority of IT software was developed by independent companies without cooperation or sharing resources. The software developers secured their information and commercial secrets by “fencing their properties,” so that they could keep their market advantage longer. But this type of software development approach causes interoperability problems for end-users in other industries that do not have IT support teams. A recent NIST (National Institute of Standard and technology) study, as shown in Table 1-1, indicated that the cost of inadequate interoperability in the U.S. capital facilities industry to be $15.8 billion per year. The intended audiences are owners and operators of capital facilities; design, construction, operation and maintenance, and

other providers of professional services in the capital facilities industry; and public and private-sector research organizations engaged in developing interoperability solutions (NIST 2005).

These firms face the challenge of combining software from different sources, to make the software adapt to different operations or to solve the conflicts with the existing software environment. This is the IT bottleneck faced by construction companies and software developers.

Challenges

The construction industry, as well as other industries, faces the challenge of synthesizing information and deriving insight from massive, dynamic, ambiguous and possibly conflicting digital data. A large variety of data models and algorithms have been proposed and implemented to exam data, acquire information, and derive understanding from the information. Those models, systems, and implementations usually focus on one or several aspects of the design, procurement, construction, and maintenance phases of a project. With the multitude of the interactive design systems, decision support systems, expert systems, knowledge-based systems, virtual reality and 3D/4D simulations, a construction professional faces the situation of how to select or best combine the available options to improve the accuracy and certainty of the decision-making process.

Innovation is the key to keep the modeling industry advancing. Management has been the most important asset in every firm. Looking back at model management innovator Frederick Taylor, it is noted that his single-minded devotion to efficiency stemmed from a conviction that it was iniquitous to waste even an hour of human labor when a task could be redesigned to be performed more efficiently. Taylor could spend days studying the most productive ways to shovel coal were evidence not only of an obsessive mind, but of a missionary zeal for multiplying the value of human effort. (Hamel 2007) Specifically, the adoption of IT in a construction company should help steer the business and facilitate effective decision-making.

Table 1-1. Cost of inadequate interoperability by Stakeholder Group by Life-Cycle Phase (in $ Millions) (NIST 2005)

Stakeholder Group	Planning, Engineering, and Design Phase	Construction Phase	Operations and Maintenance Phase	Total
Architects and Engineers	1,007.2	147.0	15.7	1169.8
General Contractors	485.9	1,265.3	50.4	1,801.6
Specialty fabricators and Suppliers	442.4	1,762.2	-	2,204.6
Owners and Operators	722.8	898.0	9,027.2	10,648.0
Total	2,658.3	4,072.4	9,093.3	15,824.0

Source: RTI estimates.

When users collect and examine data in models or systems, the goals are to retrieve information, to derive understanding from the information, and to facilitate effective decision-making. For effective decision-making, information needs to be collected from multiple categories or disciplines. For the heterogeneous data from various data sources, there are discussions about the systematic ways or methods for information retrieval, evaluation, quality-assessment, and analysis. All these procedures of information treatment serve the purpose of finding the optimized the solution to the practical problems in real world. All these require interdisciplinary research collaboration with the focus on analytical reasoning facilitated by interactive visual interfaces.

Research Problem

There are high requirements to the steel iron worker personal skills for steel connections, which limits the innovation of steel erection methods and management. In addition, variances of iron workers' performances bring in lots of job mistakes and safety accidents. Erectors need to make decisions on the steel connections, equipment selections, labor arrangements, operation, and loading problems. Project manager needs to make decisions on the arrangement of subcontractor work sequences, project control, safety, and quality. In order to solve these problems, many software companies have developed BIM tools for construction use. These BIM tools have integration problems and may conflict when used together for a single project.

The focus of this research is to investigate the framework of BIM/RFID to assist decision-making in construction project management. This research proposes to use information visualization in steel structure projects to display a model of using web-based RFID and real-time 4D BIM and MSI for the steel fabrication and erection sequence. It aims to maximize functions software and hardware and to improve compatibility of those software and database used in construction projects by using BIM/RFID system. This study would show how the structural steel identification system, such as RFID, would combine BIM and MSI to reduce mistakes in steel fabrication and erection. It helps to control multi-duty projects easier.

CHAPTER 2
LITERATURE REVIEW

Background

This chapter discusses the current trends in the construction Information Technology (IT) research and the industry needs. The literature review will first discuss the web-based project management in the construction industry. Then this chapter is going to discuss: virtual reality modeling (VRML), Industry Foundation Classes (IFC), CIS/2, Building information Modeling (BIM) and Revit, Radio Frequency Identification (RFID), the 4-D Project (Navisworks), Manufacturing System Integration (MSI), and data visualization techniques. Based on the understanding of these concepts, this research will develop a model for combining these systems in a BIM/RFID framework to assist fabrication and erection in the construction of steel structures.

Currently BIM software can be used to generate visual representations for construction projects, but BIM models cannot be used to develop and store the whole project information. The use of advanced management methods together with system integration techniques should give project managers better tools to accomplish their tasks.

There are several trends in Information Technology (IT) in modeling design that affect the construction industry. Examples include construction software for design and development purposes, to be more specific, those software products include professional specification software or construction scheduling and estimating software. Other examples include web-based construction project management software; simulation by using computer visualization models; and BIM. These software products are updated frequently. Intense competition pushes software developers to improve their designs and make their software more functional and user-friendly.

Steel Structures Concepts and Components

Design of Steel Structures

During the development of iron and steel as engineering materials, material-testing showed the advantages of using these materials in structural analysis and design. The features of these materials made it possible to transit the structure design from state of art to applied science. It was Hooke (1660) who developed the concept that load and deformation were proportional, and Bernoulli (1705) introduced the concept that the resistance of a beam in bending is proportional to the curvature of the beam. Bernoulli passed this concept on to Euler, who in 1744 determined the elastic curve of a slender column under compressive load. In the 1800s, important developments in steel structure design included: (1) Manufacture of mechanical strain-measuring instruments that made possible the determination of the elastic modulus that related stress to strain, (2) Correct theories for the analysis of stress and deformation resulting from either the bending or twisting of a structural member, and (3) The extension of column-bucking theory to the bucking of plates and the lateral-torsion bucking of beams. (Johnson 1974)

The above-mentioned advantages of steel enabled the development of engineering specifications built around the allowable-stress methods of selecting structural members. The first general specification for steel railway bridges was developed in 1905. The first highway bridge specification was developed in 1931. In 1923 the AISC (American Institute of Steel Construction) published its first general specification for building construction. Under each of these specifications, the process and criterion of acceptable design are as follows: first, calculating maximum stress; secondly, assuming elastic behavior up to anticipated maximum loads; thirdly, keeping actual stress lower than a specified allowable stress. The allowable stress is intended to be less than the stress causing failure by a factor of safety.

During the past half century, AISC has developed the design factors to standardize the design of steel structure, to evaluate the inelastic properties of materials, and to directly calculate the ultimate strength of a member. Load-factor design and other design features can be calculated as the results. This is a realistic, direct, and natural procedure. The load-factor approach has been used for many years in aircraft design. Part 2 of AISC, introduced the load-factor design in 1961. This approach is an acceptable alternative to the allowable-stress procedures for the design of continuous frames in building structures.

Steel structure design and construction include: manufacturing, fabricating, connecting, delivering, and erection. Safety issue is critical in the whole process of steel structure design and construction. Structural steel construction safety is a result of careful design, well fabrication arrangement, construction methods and management. In the design process, the risk of failure is evaluated and the probability of its occurrence is kept at an acceptable level. The exact number of the safety factor depends on the importance of the structure, risk to human life, and other factors. Evaluation of safety uses these factors. Variable or uncertain loads, such as those due to wind, flood, and earthquake are also considered for the evaluation of safety.

The Types and Shapes of Structural Steel

As tension members, structural steel items basically have seven shapes: angle, tee, W/S/M shape, pipe, double angle and double channel (single plane truss members), build-up plate and angle shape (double plane truss). Columns and compression members use difference types: round and solid bars, steel pipes, box section and structure tubes, angle struts, structure tees, wide-flange shapes, columns with lacing, battens, or perforated cover plates.

There are three types of steel which are normally called for construction: mild steel, high tensile steel and weather resistant steel. Different grades mean various steel types which are included in reference manual.

Control of Quality

As a part of the quality-control system, standards are usually adopted by agreement of trade associations. Official and semiofficial standards are organized by the National Bureau of Standards, the Department Commerce, and a network of engineering testing laboratories and inspection services spread throughout the country. These originations are not only controlling the quality of steel structure, but also keeping the improvement of steel structure technology. The following are some organizations related to structural steel standards: ASTM-American Society for Testing and Materials, AISC-American Institute of Steel Construction, AWS-The American Welding Society, ICBO-The International Conference of Building Officials, AISI-The American Iron and Steel Institute, AASHTO-American Association of State Highway and Transportation Officials, ANSI-American National Standards Institute, AREA-American Railway Engineering Association, API-American Petroleum Institute, Etc.

Drawing and Codes

Code and design specifications are a part of the professional and societal system for regulating construction. Engineers must understand them as both constraints and tools in design practice. The 1982 Uniform Building Code consisted of 48 chapters and 14 chapter of appendix (1982UBC). Codes and specifications attempt to define minimum acceptable levels of safety and translate them into design constraints.

Engineer drawings and workshop drawings

Engineer drawings are the drawings which describe the engineer's requirements and show steelwork in an assembled form. Usually they give all leading dimensions of the structure including alignments, levels, clearances, member size, and steelwork in an assembled form.

The purposes of engineer drawings are: (1) to create a basis for the engineer's cost estimate before tenders are invited; (2) to invite tenders upon which competing contractors' base their

prices; (3) to instruct the contractor during the contract including any revisions and variations; (4) to make progressive payments for the contractor based on the work completion.

Workshop drawings are defined as the drawings prepared by the steel contractor showing each and every component or member in full details for fabrication.

Steel layout and design the shop drawings

Specifications give the simple and precisely direction to the procedures for the design of main members, such as beams, columns, and tension members. Structural engineer is called upon in the design of the connecting details between members and their supports for the greatest judgment and design skill. All designed structure loads must be transmitted through successive connections from points of application down to the footings. For each succeeding components of structure must carry the accumulated dead weight of tributary components, and in preliminary design studies these weights can only be roughly estimated.

The elimination of bending or eccentricity in local elements is important. As one example, if a column is carried on top of a beam, the webs of the column and beam should be in alignment; but since the major load in the column is carried in the flanges, the flanges should in turn be supported by bearing stiffeners that are directly beneath. Thus the load is transmitted from point throughout the structure in the most efficient manner without possibility of local failure.

Marks for erection and connection special marks

Steel marks are used for member identification and erection verification. But marks also bring some problems for jobsite operation because fabricators and erectors are using self mark systems to defer the steel and parts. On beams the mark should be located on the top flange at the north or east (right-hand) end. On columns the mark should be located on the lower end of the shaft on the flange facing north or east. On vertical bracings the mark should be located at the

lower end.

The fabricator indicates where an erection mark is to be painted on a detailed drawing. The work mark contained in a rectangle shall be shown on each detail with an arrow pointing to the position required. Although workers pay attention to steel marks, many mistakes have been attributable due to appearance problems of the marks or other uncertain things. In this research, the author focuses on steel RFID identification system to resolve those problems and improve the jobsite management. (see Appendix C)

Steel Structure Supply Chain

Because the manufacture of structural steel is a complex and larger project, the planning of steel structure construction always becomes a big challenge for contractors.

The step-by-step procedures and documents that are normally as follows:

Step 1: Bidding

- The architect and engineer provide contract documents: specifications, architectural drawing, structural drawings;
- The fabricator determines the amount of material required, including shapes, sizes, lengths, and work to be done. The fabricator determines the cost for the project and submits a bid.

Step 2: Post-award stage

- The fabricator who is awarded a contract is provided with architectural and engineering drawings that are approved for construction.
- The fabricator develops a material list itemizing the steel requirement for a particular job. The list is arranged in to similar structural shapes and plates to order material from the mills in the most efficient manner. The fabricator also considers possible extra costs which may be based on: shape, length, quantity, and grade of steel.
- Development of connection details

(a) The fabricator's engineering department isolates all connections that are not standard connections or are not fully detailed on the structural engineer's drawings.

(b) The fabricator's engineer sizes connection material, for nonstandard connections, in accordance with the loads shown on the structural drawings. This includes general configuration, size of plate and angles, number and size of bolts, and length and location of

welds.

(c) Connection details are submitted to the structural engineer for approval before shop detailing has substantially started.

- Preparation of the shop drawings

(a) The fabricator's detailer draws a drawing for each piece of steel to be fabricated showing the specific work to be performed. The drawing shows general configuration, holes locations, plates, connection angles, bolts, copes, weld sizes, and so on.

(b) The fabricator checks shop details, particularly for general fit and dimensions.

Step 3: Architect's and/or structural engineer's approval

- The fabricator submits shop drawings to the structural engineer for approval.
- Shop drawings are reviewed for:

(a) Correct interpretation of structural drawings

(b) Correct size of supporting members

(c) Correct number of bolts in connections (Shop and Field)

(d) Correct amount of weld

- The Structural engineer returns shop drawings to the fabricator with comments and status, as follows.

(a) Approved as submitted-proceed

(b) Approved subject to comments-proceed

(c) Rejected-corrections must be made and shop drawings resubmitted.

Step 4: Erection plans

The AISC certified erector is required to prepare a "Project Specific Erection Plan". These plans are often prepared by the erector's engineer, including what cranes will be used to pick up what pieces, where to start, how to plumb the building, when the bolts have to be tightened before you can add more steel to the structure, etc. If the job is complicated, perhaps a structural engineer who understands steel erection should be employed to prepare the plan including:

- Description shows the steel erection where each piece is to be installed and the field welding required.
- Erection plans are developed simultaneously with the shop details. The location and the number of the piece are immediately recorded on the erection plan.
- The erection plans are submitted to the structural engineer in various forms of completion. It is the only document that correlates shop drawings to field location (and consequently, the location shown on structural drawings).

Mill-Fabrication

Structural steel shapes are manufactured at rolling mills and shipped to steel fabricating plants where the pieces are prepared for a particular building project. The fabricating process is fairly complex and requires a number of exacting procedures. The fabricator of structure steel must first, based on the structural drawings, order the appropriate shapes in the necessary lengths from the steel mill. The fabricator must then prepare detailed drawings showing exact lengths to be cut, holes to be drilled or punched, items to be welded, and so on, so that the fabrication shop can prepare the pieces properly before they shipped to the job site. The details of every piece must be shown and dimensioned accurately at shop drawings and are to fit together properly at the job site. These must be prepared in strict accordance with the architect's and structure engineer's drawings.

Pre-Erection with contractor or subcontractor

The erection process is usually complex depending on the size and configuration of the building and variety of equipment and techniques that must be employed. Essentially, during the erection process, the steel members that have been fabricated are placed in their proper position in the building frame. The erection of the frame may be done by the steel fabricator or subcontracted. There are several issues that must be considered to the proper positioning and securing of the fabricated pieces, such as the manner in which the pieces will be shipped to the building site, the ship route and maximum size of shipping requested, whether large piece

assembly take place at building site or shop, site conditions must also be considered, the necessary erection equipment needs to be considered from access to move out to job site. It may also be necessary to develop a schedule for the erection process, coordinating with other trades involved in the construction of the building. Consequently, an erection scheme may need to be developed simultaneously with the fabrication process.

Erection plan

A steel erection follows an erection plan, which is prepared by a fabricator. The erection plans are similar to the structural framing plans. It is a two-dimensional line drawing showing the framing at each floor, and where the sides of the building involve more than simply columns, a line drawing of the building frame elevation would be included. The erection plans indicated the location of each piece of steel to be placed, and each piece is marked with a letter or number or a combination of both.

Sequences of Fabrication and Erection

The use of welding requires careful and competent inspection both with regard to procedure and finished product. Both shop and field inspections of welding are important, as the quality of welds depends to a large extent on the skill, character, and endurance of the welder. Punching of holes, sub-punching with reaming or drilling should be employed to company with bolting or riveting connecting.

Automatic machines are using at shop to do such jobs to improve the effective and deduct the damages of materials. In the case of shop assemblies joining several different plates or members, economy may be achieved by clamping the pieces into a single “pack” for single or multiple drilling through all pieces in one operation. Drilling provides smooth edges of holes and the best possible resistance to repeated load.

The arrangement, number, type, and location of field splices and connections should be planned so as to avoid unnecessary duplication of construction equipment and provide the simplest possible erection plan with a minimum of field work. Connections should be arranged to facilitate field assembly. A detail, well-thought out construction plan will do the most to minimize the total cost of the project. A definite erection plan should be generated, but the contractor should have freedom to exercise their own ingenuity through alternative schemes that meet the approval of the owner.

One cause of failure occurs during the lifting operations of trusses and girders, which are normally in tension, because they may be placed in compression with consequent possible buckling failures. Even after the main frames and members are successfully placed in the structure, failures have occasionally occurred because of the haste with which construction of main framing has proceeded without attention to the walls and roof, after permanent bracing, roof, and walls are in place, the wind load resistance of the structure will be greatly increased. In the case of very long plate girders used in bridge construction, experienced contractors typically provide special horizontal temporary truss systems fixed to the plate girders for use only during erection. Although erection is normally the responsibility of the steel contractor, the design engineer can help in complex cases by scheduling the bracing that must be supplied as the construction is in progress. Alternatively, the contractor may be required to submit erection procedure plans to the engineer for approval. Construction failures are usually caused by lack of space frame stability and many more failures occur during erection than service of the finished structures.

The Technique Developed and Used in Steel Structure

There are many companies conducting research on creating some software to improve construction management level. Autodesk, VersaCaD, Summagraphics, Microstation and other

companies developing CAD has changed the tradition of architecture design methods so that designer can get rid of physical ruler and paper. Adobe 3D MAX gave the first 3D simulation picture of project.

According to Eastman (1999), computer-aided design is dependent on three different types of technologies: display technology, processor capability and software capabilities. Beginning in the mid-1950s, computer applications were written to automatically calculate engineering formulas that had previously been calculated manually. Later, CAD companies developed and used several other display technologies, including storage tubes (principally sold by Tektronix) and plasma displays.

In the late 1970s, pixel-based bitmap displays became available and within a few years grew to dominate the display market. Up to the middle 1980s, CAD systems were developed for mini-computers or time-shared mainframes. After 1990s, internet and IT technique development bring CAD to a fantastic level. PC solids modeling and Virtual Reality make construction industry a virtually and paperless world.

Currently, there are quite a few trends in Information Technology (IT) construction research and modeling design that affect the construction industry. Examples include construction software for design and development purpose, such as professional specification software or construction scheduling and estimating software. Other examples include Web-base construction project management software, simulation by using computer visualization models, and Building Information Modeling (BIM). These software products are updated frequently. Intense competition pushes the producers to improve their designs and make their software more functional and user-friendly.

Web-based Project Management

The Internet provides a platform for web-based construction project management models. Figure 2-1 shows an example of using a web-based project management service in the coordination of construction processes. Such services include web-based project management provided by e-builder; BuildIT provided by BuildIT systems; @task (http://www.attask.com); and ProjectDox provided by Avolve Software. (http://www.projectdox.com).

Web-based visualization is an advanced system that uses HTML or other means to transfer computer graphics and 3D visualized information. The computer graphics and 3D visualized information are transferred to web-based databases. (see Figure 2-1)

Figure 2-1. Web-base Project Management (by Avolve Software)

Visualization and VRML

VRML is an acronym for the Virtual Reality Modeling Language. Using VRML 3-D virtual worlds can be developed. The most exciting feature of VRML is that it enables users to create dynamic worlds and sensory-rich virtual environments on the Internet, including the ability to: (1) animate objects in real worlds; (2) make real worlds; (3) play sounds and movies within users worlds; (4) allow users to interact with their own worlds; and (5) control and

enhance worlds with scripts that users create to act on their own VRML worlds. Figure 2-2 explains the structure of virtual reality system.

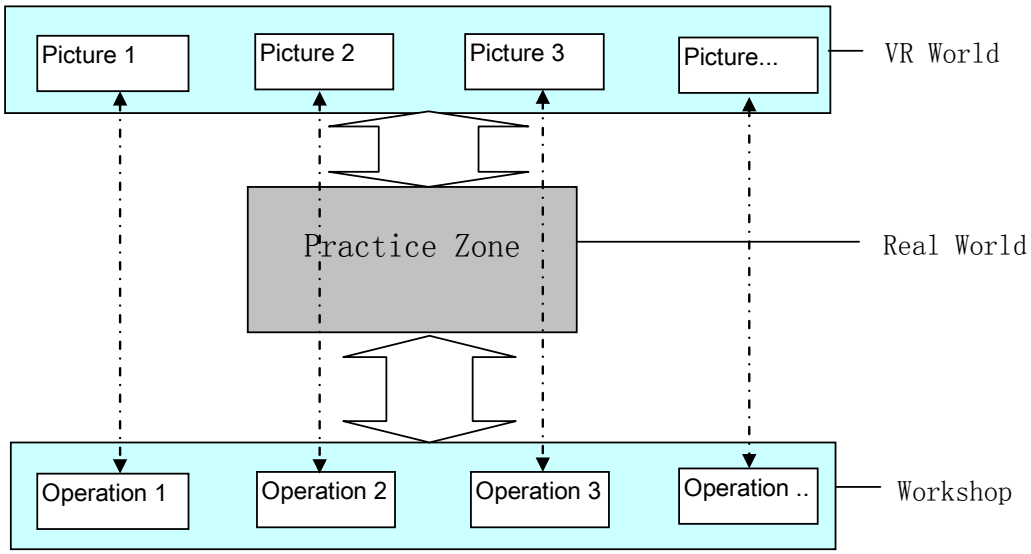


Figure 2-2. Virtual Reality architecture

The first version of VRML was specified in November 1994 (Berners-Lee 1994). This version was specified from, and very closely resembled, the Application Program Interface (API) and file format of the Open Inventor software component. The current and functionally complete version is VRML97 (ISO/IEC 14772-1:1997). VRML has now been superseded by X3D (ISO/IEC 19775-1).

The major function of VRML is to create a virtual reality environment. Its compatibility with other software products is poor. Another drawback of VRML is its difficulty to represent space on the normal computer screen instead of virtual environment around users. The advantage of VRML and its successor, X3D, is that they have been accepted as international standards by the International Organization for Standardization (ISO) (Ames 1997).

Building Information Modeling (BIM)

BIM is a set of information generated and maintained throughout the life cycle of a building. It is based on a view that the term “Building Information Modeling” is basically the

same as Building Product Model, which Eastman (2008) has used extensively in his book and papers since the late 1970s. (“Product model” means “data model” or “information model” in engineering.)

Conceptually, BIM models are object-based parametric models with a predefined set of object families, each having behaviors programmed within them. These new capabilities allow organizations to define object families in their own way and to support their own methods of detailing and layout.

BIM are characterized by building components. Those components include data that describe how they behave. For example, the behavior data include their taken-off, their specifications, and their energy analysis. The energy analysis feature of the BIM models give them great potential for the implementation of building energy efficiency analysis, green material selection, and building sustainability analysis. The behavior data are consistent and non-redundant data such that changes to component data are represented in all views of the component. Coordinated data such as that all views from a model are represented in a coordinated way (Eastman 2008).

BIM is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. BIM encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components (for example manufacturers' details).

BIM can be used to document the entire building life cycle including the processes of construction and facility operation. Quantities and shared properties of materials can easily be

extracted. Scopes of work can be isolated and defined. Systems, assemblies, and sequences can be shown in a relative scale with the entire facility or group of facilities (Eastman 2008).

Figure 2-3 and Table 2-1 show the difference between the traditional project documents and a building information model. (Leicht 2007) In the traditional project documents, plans are two dimensional, including plan view, section view, and elevation view. In building information models, a construction project can be viewed from any direction, in 3-dimensional format, and in any customer-defined scale. The HVAC system in the traditional documents is either in two dimensional plan view or isometric view.

The HVAC system in the building information models will be in 3-dimensional format and the building information models can demonstrate the quantities of the fixtures and any other quantities the user wants to know. The building information models also have the capacity to do energy analysis. The energy analysis function of building information models makes the coordination, optimization, and energy efficiency of the electrical, mechanical, and plumbing systems of buildings into reality.

BIM is able to achieve such improvements by modeling representations of the actual parts and pieces being used to build a building. This is a substantial shift from the traditional computer aided drafting method of drawing with vector file based lines that combine to represent objects.

Architectural design services mainly consist of five phases. They are schematic design; design development; construction documents; bidding and negotiation and construction administration phase (AIA B141). BIM's benefits span all phases of design. Eastman (2008) listed four viewpoints to design process, which is conceptual design, the use of BIM for design and analysis of building systems, its use in developing construction information, and design and construction integration.

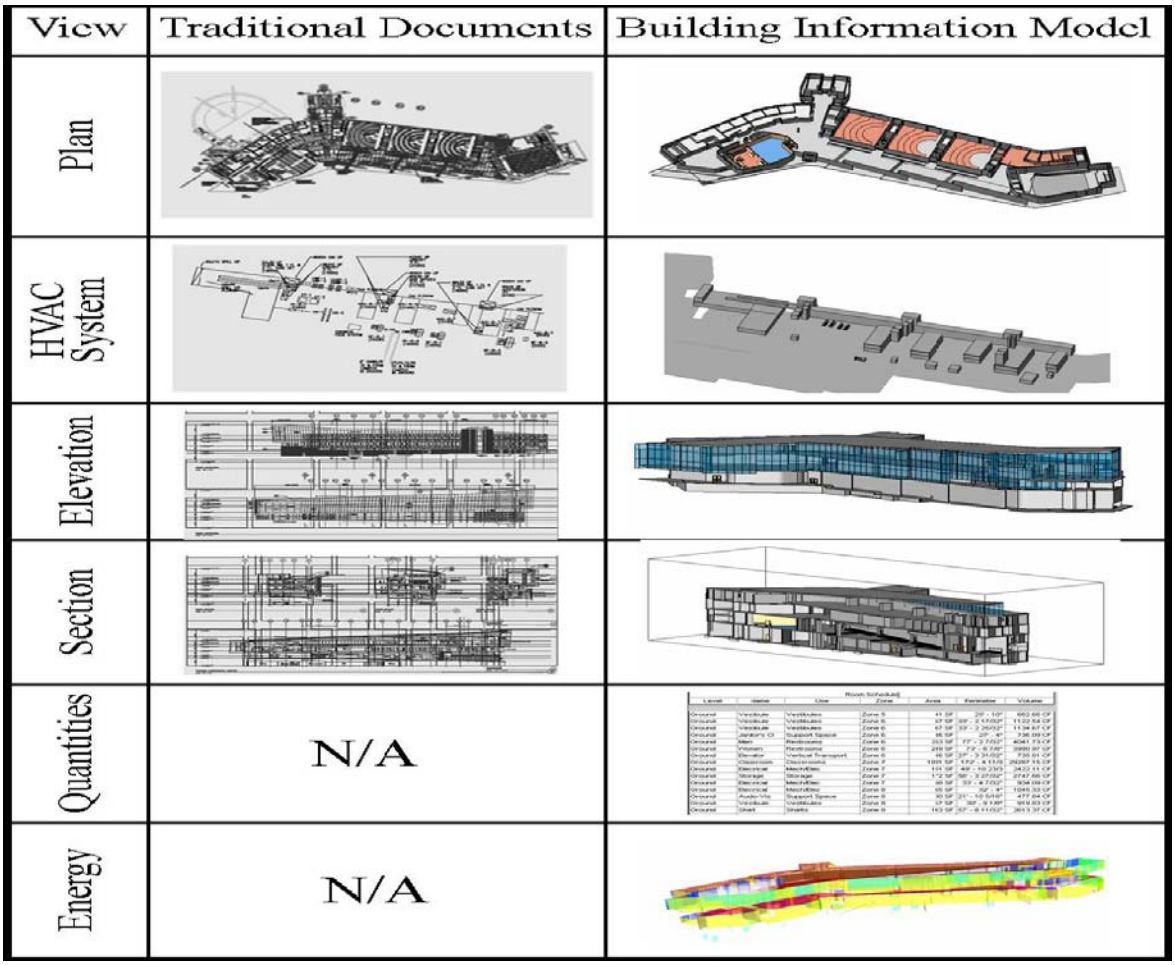


Figure 2-3. The function differences between BIM and traditional documents (Leicht 2007)

BIM is a combination of all the project data, displayed in a designed systematic model. Its functions include collection, analysis, judgment, and operation. Most building models are based on information-rich database systems.(see Figure 2-3)

They are a result of a combination of project design models, such as CAD (2D to 3D), with other AEC (Architect/Engineer/Contractor) information models. BIM has improved itself from a simple storage, sharing and exchange model to a multifunctional full-fledge work process and control center (http://usa.autodesk.com).

Table 2-1. Comparing BIM and traditional documentation (Leicht and Messner 2007)

	Traditional Documentation		Building Information Model	
Information	Form taken	How it was Obtained	Form taken	How it was obtained
Design Concepts				
Floor Plans	2D	Printed Sheets	2D & 3D	Visualized in BIM
Elevations	2D	Printed Sheets	2D & 3D	Visualized in BIM
Sections	2D	Printed Sheets	2D & 3D	Visualized in BIM
Rendering	2D	Printed Sheets	2D	Visualized in BIM
System info				
Architectural (Room Information)	Drawings & Text	Finished Schedule in Drawing & Specifications	3D Images, Text	Seen in model, properties window, or generated finish schedule
Mechanical (Duct&Equipment)	Drawings & Text	Found in Drawings & Preliminary Specifications	3D Images, Text	Seen in model, properties window
Major Material/Finishes	Drawings & Text	Found in Drawings & Preliminary Specifications	Visualized in model or plan	Properties Window or generated finished schedule
System Coordination	Not clearly evident		Conflicts in Model	Conflict report, seen in model
Other				
Description of Work	Text	Preliminary Specifications	Not Included	
Summary Room Areas	Not Included	Hand Take offs & Manual Calculations	Schedule in model	Generated
LEED information	Text	Achievable Points Listed in Specification	Not Included	
Construct ability	Drawings & Text	Determine from review of documents	Model, Plans	Determine from review of model

Current BIM software still has some drawbacks that need to be improved. One drawback is that BIM has little compatibility. There is no universally accepted standard yet. Even though CIS/2 is the first standard approved by American Institute of Steel Construction (AISC), it only applies to the product model and electronic data exchange file format for structural steel project information. The National Institute of Building Science (NIBS) developed the National Standard for Building Information Modeling (NBIMS). Most software products are proprietary, e.g. VBE (Virtual Building Environment), Virtual Building, Building SMART, AUTOCAD, VDC (Virtual Design and Construction), and Integrated Practice, etc. Each developer has their design preferences and holds on to their copyrights tightly.

Another major drawback of BIM is in its data management ability. BIM was designed for companies that use individual safe server and databases. The ability of using open data-sources

and data management in BIM is limited. In case of 3D-based BIM object information system (see Figure 2-4), BIM can be developed from a 3D model into a 4D model (3D model with schedule control). The 3D graphical model and the schedule of a project file are both information-rich, there are possibilities that some mistakes or conflicts may occur in both hardware and software. For example, lack of enough memory, program crashes, or software bugs.

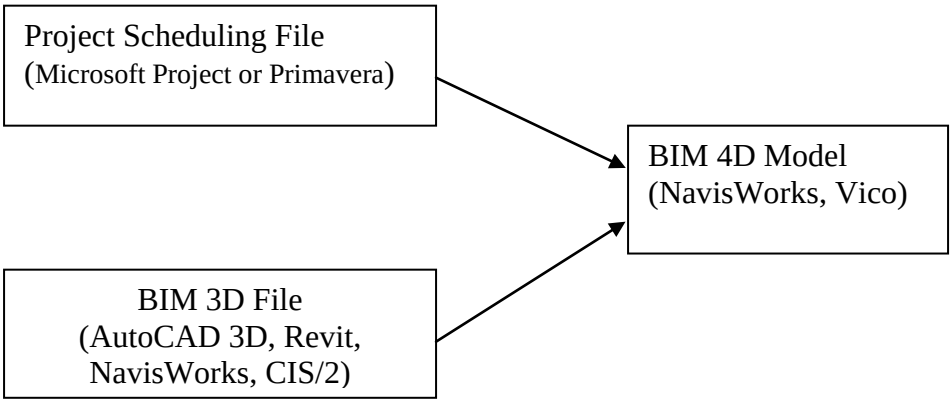


Figure 2-4. 4D Model created by BIM

The interoperability requirements relate to the inter-connection feature of the construction documents. These documents include drawings, procurement details, submittals, specifications, etc. They affect building quality. It is anticipated by proponents that BIM can be utilized to bridge the information loss associated with handing a project from design team, to construction team, and to building owner/operator. This bridging is done by allowing each group to add to and refer back to all information they acquire during their period of contribution to the BIM model. For example, a building owner may find evidence of a leak in their building. Rather than blindly exploring the entire physical building, he/she may turn to his/her BIM and see that a water valve is located in the suspect location. The model could also provide the specific valve size, manufacturer, part number, and any other relevant information.

There have been attempts to create BIM for older, pre-existing facilities. These efforts are generally referred according to their key metrics, such as the Facility Condition Index, or FCI. The validity of these models will need to be monitored over time, because trying to model a building already constructed requires numerous assumptions about design standards, building codes, construction methods, materials, etc. Therefore it is far more complex than building a BIM at the time of the initial design.

The American Institute of Architects (AIA) has further defined BIM as "a model-based technology linked with a database of project information", and this reflects the general reliance on database technology as the foundation. In the future, structured text documents such as specifications may be able to be searched and linked to regional, national, and international standards of BIM (Leicht 2007).

Manufacturing Systems Integration (MSI)

System integration was confined to the technical aspects of hardware and the interconnectivity of computing components. Integration had a mechanical connotation and piecemeal quality: making different pieces of equipment work together (Wyzalek 2000). In the past, systems integration was confined to a technical, operations task—part of the wider area of systems engineering. Today, systems integration is a strategic task, which pervades business management not only at the engineering level but also in senior management decision-making (Prencipe 2004).

The process of steel fabrication has three major steps: design –> manufacturing –> delivery. All of these are complex industrial detailed work. Steel design is comprised of architectural drawing, engineering design, and shop detail drawing. Manufacturing is comprised of steel purchasing, transferring, cutting, drilling, welding, and storing. Delivery is comprised of truck arrangement, crane arrangement, and sequence arrangement. Every part of these sequences

requires unique equipment and follows different operation rules. Some major steel fabrication companies own lots of hi-tech machines, such as digital beds or computer controlled machines. Manufacturing System Integration is a very useful system for most manufacturing operations. It is also beneficial for fabricators after making adaptations and improvements. The goal of MSI is to bring together the component subsystems into one system and ensuring that the subsystems function together as a unified system. In information technology, systems integration is the process of linking together different computing systems and software applications physically or functionally. The system integrator brings together discrete systems utilizing a variety of techniques such as computer networking, enterprise application integration, business process management or manual programming. (http://www.mel.nist.gov)

A system is an aggregation of subsystems cooperating so that the system is able to deliver the over-arching functionality. System integration involves integrating existing (often disparate) subsystems. The subsystems will have interfaces. Integration involves joining the subsystems together by “gluing” their interfaces together. If the interfaces do not directly interlock, the “glue” between them can provide the required mappings. System integration is about determining the required “glue”. (http://www.sharpy.dircon.co.uk/index.htm). System integration is also about value-adding to the system, capabilities that are possible because of interactions between subsystems.

The construction industry needs to better integrate the activities in the subsystems. The subsystems include design, fabrication, construction and operation of constructed facilities through the use of computer technology (Wilson and Bryan 1994). Integration of systems has become a topic of interest to many professionals, including those in the AEC industry. From an information systems perspective, integration can be defined as the design and development of

information systems that combine several hardware and/or software components to cooperate and carry out a joint task that would be beyond the capabilities of any one of them individually.

System integration in the AEC industry can be applied at three levels:

Inter-application integration. This involves combining the computer applications of one company into one integrated system. These applications can then share data and call each other's procedures.

Inter-system integration. This exists when one company's applications integrate with those used by other project participants.

Industry-wide integration. This will allow any project participant to communicate electronically with any segment of the industry (e.g., owners, designers, suppliers, financiers, regulators, etc.). It would also ensure consistency across different projects.

A more widely used term in the construction industry to represent integration is Computer Integrated Construction (CIC) (Karttam and Levitt 1990). CIC can be defined as a business process that links the project participants in a facility project into a collaborative team through all phases of a project. Figure 2-5 shows an overall CIC framework. The framework includes both computer-aided drawing/design (CADD), and visual computing and computer aided engineering (CAE) (Xie 2005).

MSI is used to bring together the component subsystems into one system and ensuring that the subsystems function together as a system. In information technology, systems integration is the process of linking together different computing systems and software applications physically or functionally. The system integrator brings together discrete systems utilizing a variety of techniques such as computer networking, enterprise application integration, business process management or manual programming. In this research, MSI will bring the Web-based 3/4D BIM

Visualization Model together and test it to make sure the functions are properly developed by proposed model.

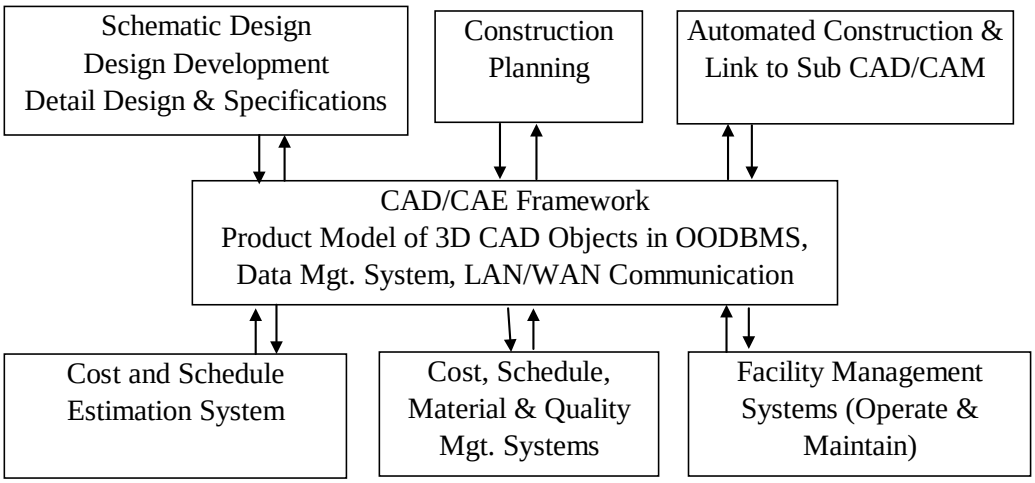


Figure 2-5. Computer integrated construction technology framework (Xie 2005)

BIM on Site

The functions involved in the use of BIM onsite are verification, guidance, and tracking of construction activities. Contractors must field-verify the installation of building components to ensure that dimensions are correct and performance specifications are met. Even when a project team creates an accurate model, human error during installation remains a possibility, and catching these errors as they occur or as soon as possible has great value (Eastman 2008). Eastman noted that the intimate knowledge gained by virtually building the project allowed the team to discover field errors. The team combined traditional field-verification processes of daily site walks with model reviews to detect potential field errors. More sophisticated techniques are evolving to support field verification, guide layout, and track installation. Some examples are as follows:

Laser scanning technologies: Contractors can use laser scanning technologies, such as laser measurement devices that report data directly to a BIM tool, to verify that concrete pours

are situated in exactly the correct location or that columns are rehabilitation works and capturing as-built construction details (GSA 2007).

Machine-guidance technologies: Earthwork contractors can use machine guided equipment to guide and verify grading and excavation activities driven by dimensions extracted from a 3D/BIM model.

GPS technologies: Rapid advances in Geographical Position System (GPS) and the availability of mobile GPS devices offer contractors the ability to link the building model to global-positioning-systems to verify locations.

RFID tags. Radio Frequency Identification (RFID) tags can support the tracking of component delivery and installation onsite. BIM components that include references to RFID tags can automatically update building product data and construction process data with links to field scanning devices. BIM combined with RFID can provide contractors with rapid feedback on field progress and installation (Eastman 2008). More detailed discussion of RFID will be presented in the next section.

The use of BIM in the field will increase dramatically as mobile devices and methods to deliver BIM information to field workers becomes commonplace. A survey (Eastman 2008) conducted in early 2007 found that 74% of US architectural firms are already using 3D modeling and BIM tools, although only 34% of those use it for intelligent modeling. BIM and 4D CAD tools are becoming common in construction site offices (Eastman 2008). BIM will contribute to a high degree of fewer documents, far fewer errors, less waste, and higher productivity, better analyses and exploration of more alternatives, fewer claims, and fewer budget and schedule overruns.

But jobsite uncertainty is the big challenge for project managers. Even in a BIM developed by a skillful technique team, one man-made mistake may destroy the successful modeling of techniques. The imperfections of the jobsite may include: missing parts, equipment damages, wrong directions, safety violations, bad operations, invisibly recognition, etc. None of them can be recovered by BIM. In these types of situations on the jobsite, an Identification Coding system is a necessity.

Steel Identification with RFID

Automatic Identification and Data Capture (AIDC) refers to the methodology of automatically identifying objects, collecting data about them, and entering that data directly into computer systems (i.e. without human involvement). Radio Frequency Identification (RFID) is one of the most popular AIDC used in transportation, security, retail, manufacturing and material delivery system. It has been used in many areas of the construction material supply chain, but it has not yet been used in the steel supply chain area. The following discussion would verify the feasibility and effectiveness of using RFID (Waldner 2008).

RFID is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. The technology requires some extent of cooperation between an RFID reader and an RFID tag. (http://www.aimglobal.org) An RFID tag is an object that can be applied to or incorporated into a product, animal, or person for the purpose of identification and tracking using radio waves. Some tags can be read from several meters away and beyond the line of sight of the reader.

That became one of the major advantages of RFID over bar code. For most bar code implementation, they need to have human involvement in holding a scanner and scan bar codes one by one. Most RFID tags contain at least two parts. One is an integrated circuit for storing and processing information, modulating and demodulating a radio-frequency (RF) signal, and other

specialized functions. The second is an antenna for receiving and transmitting the signal. In the future chipless RFID will allow for discrete identification of tags without an integrated circuit, thereby allowing tags to be printed directly onto assets at a lower cost than traditional tags. (http://www.rfidjournal.com)

RFID means the RFID tag in a smart label. It is a new high-tech technology used in retail and other industries. It comprises the chip and aluminum, copper or silver antenna bonded to a polyethylene terephthalate (PET) layer that is delivered to the label maker "dry" (without adhesive) or "wet" (attached to a pressure sensitive liner). The inlay is adhered to the back side of the label and printed and encoded in an RFID printer. (http://www.pcmag.com)

RFID involves the aluminum and copper antennas. But that may cause a problem especially for steel structural items, because metal items and liquids in a carton "detune" the tags and impede backscattering. One way to solve that problem is to use a smart label containing the RFID tag as well as printed bar codes and alphanumeric characters. The printed material can provide redundant UPC and EPC data that can be picked up by a bar code scanner or read by a warehouse employee if the RFID tag cannot be read. RFID smart labels are printed and encoded at the same time in an RFID printer.

ERA (European Research Area) in its report discussed the implementation of RFID with the focus on logistics and supply chain management. RFID in construction offers a new method for industrial innovation and efficiency improvements, but there are still some considerable obstacles: (ERA 2006)

- Immature application of advanced logistic systems and the absence of information and identification systems in the construction industry;
- Lack of awareness of RFID's potential in the construction industry;
- Low RFID knowledge and awareness in the construction sector;

- Lack of robust RFID initiatives in the construction industry;
- Lack of successful RFID implementation cases that thoroughly show its potentials;
- The traditionally construction industry and its relatively negative attitudes are towards new innovations and technology.

RFID technology has a data memory function. It has been used in the passport and identification (ID) checking system since 2006 in UK. The microchip in the passport can store personal information like the passport number, the holder's date of birth, the passport expiry date, etc. Even the biometric image can be contained on the printed page of the passport on a "machine readable zone (Guardian 2006).” It is possible to have more information stored in RFID tags or chips in the future and to track information by simply using a reader without a platform of RFID database from computer system.

Table 2-2. RFID performance advantages and disadvantages

	RFID Performance	
Descript	Advantage	Disadvantage
Technique	Maturate technique after twenty more years developing	Passive Wave Range limitation of about 20 foot.
Accurate	Good enough for building jobsite work.	More exactitude more cost. The reader cost plus PDA cost usually thousands dollar.
Standard	You have option to choice the one you like among hundreds productions.	No universal standard and universal ports when change tag or reader from different factory.
Cost	Tag cost decrease after technique improved. The cheapest around 20-60 Cents and recycle able.	Reader and station price high.
Implementation	Widely using at retail, auto industry for supply-chain.	Inconvenience for multi-transaction task when transfer data from different user because of confliction of software or missing connection ports.

Table 2-3 shows the use of RFID in the different systems. In this table, the advantages and disadvantages of using RFID in these software systems are discussed. Most of them are BIM tools. After using RFID, the noticeable help is the improvement to their components’ identification and tracking functions. This is very important to digital transaction and data collection.

Table 2-3. RFID specification and concepts (http://data-acquisition.globalspec.com 2008)

RFID Specification		
Type	Tag / Transponder	A microchip attached to an antenna that picks up signals from and sends signals to a reader. The tag contains a unique serial number, but may have other information, such as a customer' account number. RFID tags can be active tags, passive tags and semi-passive tags. RFID tags are sometimes referred to as transponders.
	Reader	The reader communicates with the RFID tag via radio waves and passes the information in digital form to a computer system.
	Antenna	The antenna is the conductive element that enables the tag to send and receive data. Passive tags usually have a coiled antenna that couples with the coiled antenna of the reader to form a magnetic field. The tag draws power from this field.
	Transceiver	Transceivers both receive and transmit data.
	Printer / Encoder	RFID are used to encode RFID tags.
	System	A system includes both a reader and tags. A system can also include a printer / encoder.
Technology	Passive	An RFID tag without a battery. When radio waves from the reader reach the chip's antenna, it creates a magnetic field. The tag draws power from the field and is able to send back information stored on the chip.
	Semi-passive	Similar to active tags, but the battery is used to run the microchip's circuitry but not to communicate with the reader. Some semi-passive tags sleep until they are woken up by a signal from the reader, which conserves battery life.
	Active	An RFID tag that comes with a battery that is used to power the microchip's circuitry and transmit a signal to a reader. Active tags can be read from 100 feet or more away.
Interface	RS232	Interface between data terminal equipment and data communications equipment employing serial binary data interchange.
	RS422	RS422 is a balanced serial interface for the transmission of digital data. It was designed for greater distances and higher Baud rates than RS232.
	RS485	RS485 is a balanced serial interface for the transmission of digital data. The advantage of a balanced signal is the greater immunity to noise. The difference between RS422 and RS485 is that RS485 can be transformed into a multi-point application.
	I²C	Inter-Integrated Circuit (I²C) is a bus is an inexpensive type of chip interconnection that is popular on circuit boards (pronounced "Eye Squared C").
	TTL	Transistor-transistor logic (TTL) is a common type of digital circuit in which the output is derived from two transistors. More commonly, however, TTL is used to designate any type of digital input or device.
	USB	USB products (Universal Serial Bus) is the original standard that supports data transfer rates of up to 12 Mbps.
Performance	Frequency	RFID products use low, high, ultra-high and microwave frequencies. Each frequency has advantages and disadvantages that make them more suitable for some applications than for others.
	Memory	The amount of memory controls the amount of data that can be stored on a tag.
	Read Rate	The maximum rate at which data can be read from a tag expressed in bits or bytes per second.
	Detection Range	The distance from which a reader can communicate with a tag. Active tags have a longer read range than passive tags because they use a battery to transmit signals to the reader. With passive tags, the read range is influenced by frequency, reader output power, antenna design, and method of powering up the tag.
	Operating Temperature	The range of temperatures through which the RFID product is designed to operate.
Features	Portable	The RFID reader is not a fixed system.
	Read / Write	RFID tags that can store new information on its microchip.
	Anti-collision / Multi-read	A general term used to cover methods of preventing radio waves from one device from interfering with radio waves from another. Anti-collision algorithms are also used to read more than one tag in the same reader's field.
	Non-contact	Reader can operate without physical contact with the tag being read.
	Encryption	A system that scrambles its data to prevent unauthorized duplication.
	Continuous Reporting	A mode of reader operation where a transponder ID is reported continuously while that transponder remains in the field of the reader.

When selecting RFID transponder integrated circuits, the primary selection criteria are memory size, transaction speed, communication range and cost (Dressen 2008). CryptoRF® is the world's first 13.56 MHz RFID devices with a 64-bit embedded cryptographic engine, dual authentication capability, and up to 64 Kbytes of memory, each with up to 16 individually configurable sectors (http://www.atmel.com 2009). It is possible to integrate RFID technology with AUTOCAD, TEKLA, DESIGN DATA, VELA SYSTEMS and other systems in USA in steel frame building design in construction companies.

The RFID real time location system is a newly developed technology. ITEC Corporation is a leading Electronics Manufacturing Service (EMS) provider for the RFID and wireless communications industry. It provides an overview of its “I'm Here” active RFID real-time location system (RTLS), which the firm has deployed within its own manufacturing facility in Nagano, Japan.

Another way to solve “backscattering” problem is to use active RFID. As a forefront wireless technology, active RFID is still not effectively integrated in many cases, but it will give big benefits to the construction industry tomorrow. ITEC’s Active RFID Model Factory 1.0 solution is based on technology jointly developed with its U.S. business partner, RF Code, and utilizes RFID tags placed on critical assets and RF readers placed in key locations to monitor manufacturing processes and staff activity. RF Code is a leading provider of real time RFID asset tracking solutions in the U.S. (http://www.itec-america.com)

Active RFID technology has wide implementation in the construction industry. Active RFID technology supports the visibility of high-value assets, such as trailers, excavators, forklifts, light towers and other construction equipment. For example, it can pinpoint the location of heavy equipment for monitoring and control. It can facilitate emergency evacuation of

hazardous sites, asset tracking, and access control. Active RFID can automate order fulfillment in leasing operations, for better asset availability condition, greater receipt/billing accuracy and higher customer satisfaction. Active RFID can also locate personnel in real time and control access to restricted areas and equipment for increased personnel safety and equipment security.

With its long read ranges and ability to perform in harsh, wet and metallic environment, active RFID technology can be implemented to the following construction situations (http://www.wavetrend.net/industries_const.aspx):

- Automated construction equipment leasing/plant hire
- Inventory control and stock distribution
- Access control to sensitive areas/equipment
- Emergency personnel recall and evacuation
- Time and attendance management
- Out of hours security at construction sites

Overcoming these barriers depends on the development of an integrated approach between technical organization, training programmers, competences and management (ERA 2006). The advantages and disadvantages of RFID are listed in Table 2-2.

Many research projects have shown the potential of RFID application in various areas of the construction industry, such as concrete operations, labor management, productivity analysis, construction tool tracking, and pipe spool tracking. Some trials have shown that RFID in the structural steel work enabled more accurate logistics and progress management, and that this could lead to the reduction of risks, including material loss and schedule overrun, by monitoring the erection process on a steel member unit basis. RFID combined with 4D PMS (RFID+4D PMS) offered more efficiency in process time and in stockyard duration than the existing process, and thus saved time and money (Chin 2008).

Web-based computer software facilitates long distance communication between the offices of the AEC team members. BIM would be the very convenient tool for the AEC industry in providing a paperless and information rich reference to track the progress of a real project. The use of RFID+4D adds more elaborate data and visualization detail to the project. This research is going to look at the advantages and disadvantages of each methods and how to combine their functionality synergistically to assist in the fabrication and erection of structural steel components. The use of BIM and the above described synergistically functionality systems facilitate the selection of the optimization plan and help manager make the right decision. In the proposed system, the framework design will focus on the steel structure fabrication and erection.

Steel construction can be divided into four continual processes: Structural Design, Detailing and Estimating, Fabrication, and Erection (installation). (www.aisc.org) The process of structural steel installation generally includes: base-plate and base concrete setting, column erection, beam erection, bracing, joist and truss installation. Planning and scheduling may be complicated if a project has lots of steel items to install. Two methods can be used to show a project schedule. One method is to use different colors to distinguish the different parts, such as columns, beams, bracings, or trusses. Special colors can also be used to mark the finished jobs and going-to-finish jobs. For example, use green for all columns not installed and yellow for the installed columns; for beams, use red for the un-installed and orange for the installed. Other pieces such as plates, angles, channels, and tubes, can also be marked by selected colors (see Figure 2-6).

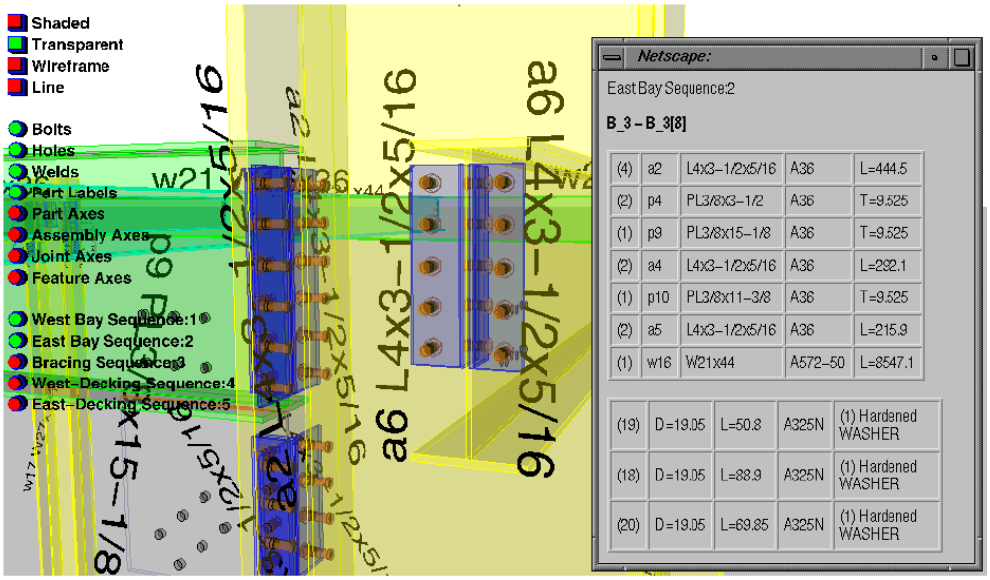


Figure 2-6. VRML model with several display features (Lipman and Reed 2003)

Another method is to use serial numbers to distinguish steel parts which have RFID tags. A hand-held scanner may be introduced into the proposed model depending on the specialty of the steel erection sequence. It will be configurable with different computer systems and scheduling software. When using RFID, from the first piece steel of the project to the last one installed, all users involved can track it the first time. By checking the data from the scanner, users can find out whether a job has already been done or is still ongoing. So a project supervisor can use it to check the daily project progress and organize activities to follow the schedule. Users can also find all related information for each part as well.

For example, Code# 125013 means: Column#3, W12x120, two holes need to be drilled for safety belts on each floor, 6 bolts connection with two W12x40-4 cut flanges, one L3x3x1/2 on second floor, one W12x26-4 cut flange and L 3x3x1/4 on third floor, one moment connection with W10x65 on second floor, and so on. Figure 2-6 is an example for a VR model showing the information of different pieces of steel.

On the left side of the image in Figure 2-6 are buttons to change the rendering mode and switches to turn on and off the views of bolts, holes, welds, labels, axes, and sequences. The steel members are displayed in a transparent mode with a wire frame outline. In this mode, the blue clip angles are visible through the yellow column. In the bottom left is a gray gusset plate with six holes. Each of the parts has a text label consisting of its piece name, size and section type. The label floats above the part and always faces the viewer. On the right, a text popup appears when clicking on any part in the model. The popup contains information about all of the parts in an assembly. The first line indicates which sequence the assembly is part of. A sequence is any group of assemblies. The second line is the mark of the assembly. The first table contains information about all of the parts in the assembly. The columns of the table are: quantity, piece mark, section type, material grade, and length or thickness. The second table contains information about the bolts used in the assembly. The columns of the bolts table are: quantity, bolt diameter, material grade, and quantity and type of washer (Lipman and Reed 2003).

The key to implementing this model is using RFID (Radio-frequency identification) techniques. This research suggests that RFID tags should be used after the first step of fabrication when the major structural steel are cut and other minor components(i.e. plates, angles, trusses) are made. The RFID technique should also be used for the steel structure erection. The scanner is used to scan each piece of the steel structure with a RFID barcode, at least for main column and beams. After the job is done, each piece of information scanned will be translated into a code that represents the steel. Then the data will be imported to the information system and change the color of steel in 4D VR model system. This serial-code system is different from the bar-code system, which is used in fabrication and erection by some companies. The serial-code system is not just a tracking code; it is part of the proposed real-time

4D-VR system. It has a broader site management perspective, aiming to deal with not only day-to-day but also item-to-item activities. This method can be used for all steel parts, even for plates and bolts. The code can be developed by adopting an existing bar code system or by creating a new standard to reflect the workflow or the supply chain.

Today, RFID is used in enterprise supply chain management to improve the efficiency of inventory tracking and management. However, growth and adoption in the enterprise supply chain market is limited because current commercial technology does not link the indoor tracking to the overall end-to-end supply chain visibility.

The workflow used in deploying RFID is shown in Figure 2-7. A manufacturer puts a code on a piece of steel then sends it to a fabricator. The fabricator reads it at same time through BIM and then works on the shop drawings when waiting for the material to arrive. The storage area will reserve a place to save it. The scheduler can adjust the schedule. The jobsite manager will be informed about the parts fabricated soon. Other involved workers can see the related details of the piece of steel at real-time. After the fabricator's job is done, the piece of steel will be sent to jobsite according to the shipping schedule, everybody will know that the part was shipped out and they can plan for it. The piece of steel will then be scanned-in by a site supervisor. The above system uses a shipping RFID code control schema. The steel erection will follow an erection and crane schedule. An erector will scan the parts before erection, and will automatically enter the data into the 4D BIM system. The 4D BIM system will show whether a piece of steel has been installed or not by using the color code. When the schedule is changed, it will show in real-time on the 4D visualization model.

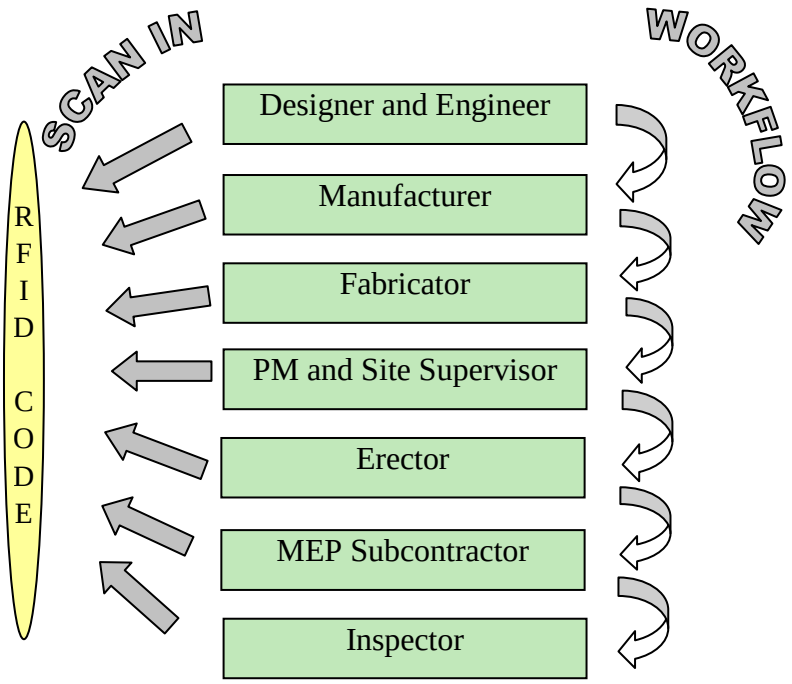


Figure 2-7. RFID coding system workflow

When an inspector visits a job site, he/she could first use this 4D virtualization model and by checking the BIM system will know what is going on at site, to see if every sequence follows the inspection requirements. Then he/she could go to jobsite to check the real details. The contractor, architect, or owner can track the results of change orders using this system and make sure the results are acceptable.

The advantage of using RFID in this model is that it can provide information to contractors and help them making judgment on uncertain things, such as missing parts, delayed orders, and misused materials. For example, let us assume the average time for a beam to be shipped out and be erected on site is one week. If the system indicates that the wrong beam was shipped on site, then that means there is a one week buffer to reorder or adjust the work sequence.

Steel erection needs a precise and safe operation solution. A laser based Robotic Total Station may be used in steel erection depending on the need for 3D mechanical, electrical, and plumbing (MEP) layout function. With the Trimble MEP layout solution, mechanical, electrical,

and plumbing contractors can increase productivity and simplify the layout of sleeves and hangers. Trimble MEP enables mechanical, electrical and plumbing contractors to take 3D positional data to the field digitally, increasing productivity and accuracy by improving layout processes (http://www.trimble.com 2009).

Three basic components of GPS are used on the construction job site: absolute location, relative movement, and time transfer. In construction jobs, GPS is used in setting grading levels, shipment tracking, and site layout, etc. But a normal civilian-used GPS system, the accuracy is in the meter-error range. This limits the use of GPS used in survey or level grading that requires accuracy. Recently, Topcon has made millimeter accuracy in its new product: Millimeter GPS. This new tool can limit accuracy in 10 Millimeter which is adequate for most precision and productive uses.

Millimeter GPS+ combines the advantages of laser (multi-user and high vertical accuracy) with GPS (multi-user and 3D) into one versatile and easy to use system. This patented technology improves grading accuracy up to 300% over existing 3D-GPS machine systems (http://www.topconpositioning.com 2009). Both RFID tags and GPS receivers have been handling the important work of tracking very well. GPS is able to transmit the location data. The device then communicates the RFID data via a unique ID and channel to any reader within 200 meters (http://rfidtimes.org 2006).

It has been found that the locating abilities of the tag locator of the Millimeter GPS+ are promising and give accurate latitude and longitude measurement. The readings are precise up to 3 to 5 meters. This is bundled in with an active RFID tag that operates on the frequency band of 429 MHz.

From the above research results, it is evident that RFID tags can help in steel erection by allowing project managers who use them to track progress in a real time 4D BIM model. The 4D BIM model will also contain information about project planning and scheduling, cost analysis, reporting, inventory management, and erection sequence management. The RFID tags will also facilitate the incorporation of data sharing and transferring into drawing, inventory, and supply chain systems.

Differential Global Positioning System (DGPS) is an enhancement to Global Positioning System that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions. (http://www.trinityhouse.co.uk 2009) The term can refer both to the generalized technique as well as specific implementations using it. It is often used to refer specifically to systems that re-broadcast the corrections from ground-based transmitters of shorter range.

The Millimeter GPS is one of DGPS type equipment. Its Laser Zone system is comprised of three components: Positioning Zone Laser Transmitter, Positioning Zone Sensor (for Mobile Rover Applications), and a Positioning Zone Sensor (for Machine Control Applications). Position zone laser transmitter sets up and operates much like a standard rotating laser (http://www.topconpositioning.com 2009).

CIMSteel Integration Standards (CIS/2)

CIMsteel stands for the Computer Integrated Manufacturing of Constructional Steelwork (http://www.cis2.org). The CIMSteel Integration Standards (CIS/2) is the product model and electronic data exchange file format for structural steel project information. CIS/2 is intended to create a seamless and integrated flow of information among all parties of the steel supply chain involved in the construction of steel framed structures. It has been adopted by the American

Institute of Steel Construction as their format for data exchange between steel related CAD software.

CIS/2 has been implemented as a file import or export by many steel design, analysis, engineering, fabrication, and construction software packages. A CIS/2 file exported by an analysis or design program can be imported into a detailing program to design the connections. CIS/2 itself is not a software package with user interface. The user will see it as file format. CIS/2 data format can be used for import or export functions in steel related CAD software.

The CIS/2 standard covers everything, including: nuts, bolts, columns, girders, and other materials. It also includes loads to frames and assemblies. Steel structures can be represented as analysis, design, or manufacturing (detailed) models in computer systems. There is a logical relationship between the different types of models. For example, a beam in an analysis model can be further subdivided into several sections depending on the load distribution pattern on it. It is logically only one beam in the detailed model. The calculation result of the load at the end of the beam will be used to design the bolts and the weld.

The use of CIS/2 and IFC is an important part of improving the efficiency of the delivery of structural steel projects in the steel supply chain. It can eliminate the redundant and error-prone reentry of the information about structural steel items. Interoperability between different CAD software packages using CIS/2 and IFC play a critical role in the wide acceptance of BIM. The National Institute for Standards and Testing (NIST) was represented on the American Institute of Steel Construction (AISC's) Electronic Data Interchange (EDI) Review Team. The review team chose CIS/2 as the standard for electronic data interchange. NIST has helped software vendors to implement the standard and helped steel designers, detailers, and fabricators use the standard. The CIS/2 to VRML and IFC Translator was also developed by NIST.

A CIS/2 file can be translated into a 3D interactive model in the form of a VRML (Virtual Reality Modeling Language) file. The VRML file can be viewed in a web browser with a free VRML plug in. The translator recognizes CIS/2 entities of analysis and detailing (manufacturing). It also models the designs. Users can visualize CIS/2 files and make them available on the Internet. Software developers can verify their CIS/2 export capabilities (AISC 2006). An example software system for structural steel is composed of Express Engine (Express 2006), Express Data Manager (EPM 2006), or STEP Tools (STEP 2006), etc. The Express Engine and data manager and tools help the detailing and design processes of steel structure.

The current method of selecting an assembly viewpoint does not lend itself to many viewpoints. The translator has a lookup table of dimensions for many of the standard section profile designators. But there are some nonstandard designators that are not in the table. If the designator is not in the lookup table or cannot be parsed, the resulting VRML will show a white member with a rectangular cross section. If the assumed units for the cross section dimensions are different than the units for the length then the cross section will be too large or small (CIS/2 2006). The VRML models were generated from CIS/2 files. The models were supplied by most of the software vendors of steel CAD software packages which have implemented CIS/2 export capabilities (Lipman and Reed 2003).

From project design to virtualization demo and 4D implementation, the above systems cover almost every aspect of construction jobs. But none of those programs can systematically go through every construction process because of various reasons. For example, CIS/2 has a few features similar to the proposed system, but it does not list 4D as a choice. CIS/2 does not have enough functions to show some parts in detail, such as bolts, plates and welding methods. Most of these problems are the targets of 3D VR models. 4D-visualization can help with planning and

scheduling. But no software or program of 4D-visualization focuses on structural steel fabrication and erection.

General Decision Making Model Description

For a decision-making model, it involves four stages in the development of the model: model framework design, model developing, model testing, and model implement. In this sequence, the first step need to do is to develop the structure of the application system and decide on what program that going to use to make the model from theory into reality.

The construction jobsite has many uncertain conditions and risks. For example, site condition change (ground sink, flooding, weather change); schedule delay (caused by Fabricator, Equipment, or MEP); labor absence; local or OSHA penalty; fabrication mistake; heavy equipment loss by theft; material missing; budget cuts; unexpected damage; and so on.

It is difficult to claim a result proposed by the system is the best one or most suitable to the project conditions. But it is possible and feasible for the system to generate a result which will satisfy the complicated criteria of the evaluation module of the system. The suggested result would have great potential or possibility to save construction time, decrease cost, improve safety record, or achieve better quality in the end of the construction process.

In the steel structure erection process, there are many factors or variables affecting the job performance. The variables in the process include: time, cost, quality, safety procedures, building code, workers' experience, etc. Different projects have different weights on the variables. For example, in a time-critical project, the time issue will be the most important factor, and hence will have the prevalent weight. For a nuclear plant construction project, safety will be the most important one in all the variables.

Generally, steel erection is a complex manufacture-delivery-installation process with great probability of failures or errors. The time, cost, and safety (Building Code and OSHA

Regulation) are always the first three considerations of a project. Those three factors can also be used to evaluate a project's performance and quality. Clemen and Reilly show a flowchart to illustrate the decision analysis process. In construction jobsite, we have 5W to help make decision: What, Where, Why, Who, When, this is the way same as to identify the problem.

Simplify these processes, a general decision making framework (DMF) for jobsite uncertainty can be use include the follow steps: (Olbina 2005)

- Identifying input independent, dependent variables, problems and required
- Testing the question by experimental, computer simulation and mathematical calculations
- Obtaining output results
- Making the decision

Most system analysis tools and approaches are based on the assumption that the computer system will have a well defined process. But different decision makers approach problem solving in different ways. (Sprague 1982) This is a challenge for system maker to build a fine system for most users but not everyone.

BIM decision making model based on systems integration and analysis results, making decision and testing system decisions by different calculation blocks. All those questions that need to be decision can have different results because of personal preferences (see Figure 2-8). For example, project management may needs a result which is good for jobsite performance when subcontractor needs a result for his benefit. In steel structure projects, the erector needs to finish his work ASAP but PM needs the project safe and fair for each subcontractor. In this case, the decision makers should have a limitation on rights adoption. Project Manager should have primary decision right when subcontractors have their decision making rights after PM's decision.

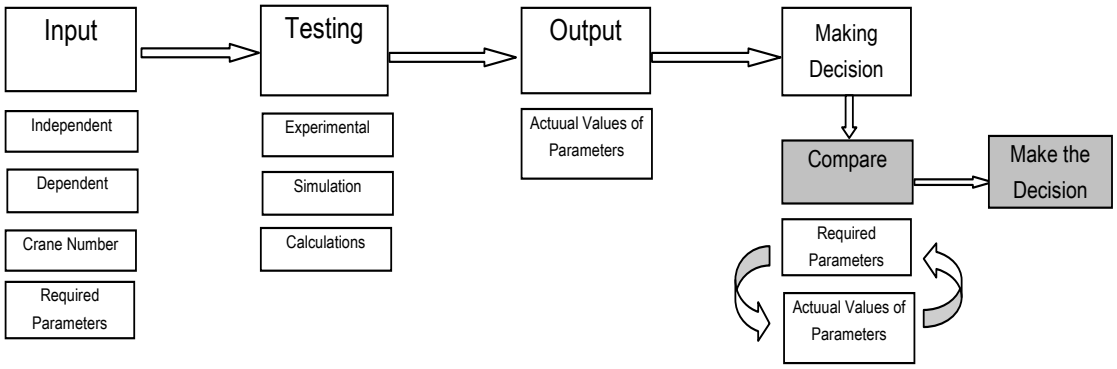


Figure 2-8. General decision-making processes

Decision Making Environments and Decision Criteria

The decision making process is a problem solving process. It should consider all management related level or positions, such as accounting, finance, human resource, production and sales, and management functions, such as planning, organizing, leading and controlling. Some decisions can be classified as programmed decision. It can be made by using standard rules or methods. If decisions rely on judgment and focus on the firm's strategic development and survival, it can be classified as nonprogrammer decisions. To deal with most complex decision problems, the rational decision making processes can be use as a simple quantity weight and optimization choice method (Dessler 2001).

Traditional, the process of decision making can come from define the program, identify and weight the criteria, develop and analyze the alternative to make a choice and then implement and evaluate the decision. The Information system is a set of persons, data, technology, and organizational procedures that work together to retrieve, process, store, and disseminate information to support decision making and control (Dessler 2001). BIM is a cooperation work station for different kinds of information system or programs, its main function is make a easy decision to deal with many resource and different creators.

The decision-making in BIM can also design as a tradition method that information system application for each organization level and project position. The BIM Phases of each organization level for a steel structure project can be separated as Design Phase, Manufacture Phase, Transportation Phase and Jobsite Erection Phase. The Decision Support System (DSS) concept was first articulated in the early 1970's by Michael Scott Morton under the term "management decision system (Sprague 1982)."

BIM decision making model are using different DSS to support it to make the decision for many kinds. In this case, Types of Systems for BIM will be Design Decision System (DDS), Manufacture Decision System (MDS), Supply Decision System (SDD) and Jobsite Decision System (JDS) to compare with those systems in Table 2-4.

The decision situations are variety and depend largely on the decision environment. The two primary decision environments are certainty and uncertainty. In a certainty environment, the best decision will always be associated with the best outcome.

The certainty environment is predicated on the fact that the outcome from each alternative course of action is known. This makes choosing between the alternatives straightforward. But the typical business decision-making environment is uncertainty. We may be able to specify the possible outcomes for each alternative, but we will be uncertain about which outcome will occur (Groebner 2008).

In construction projects, the Building Code, Land and Design requested factor can be including by the certainty environment. Some jobsite uncertainty are listing here: Site condition change; Schedule Delay-Fabricator, Equipment, MEP; Labor Absence; OSHA penalty; Fabrication mistaken, like weld a rod plate; Material Missing or Short; Budget cut; Accident

Damage. To treat with these certainty and uncertainty problems always are manager's big issue especially for those uncertainties.

Table 2-4. Applications of systems for each organizational level (Laudon 1998).

Applications of Systems for Each Organizational Level				
Strategic-Level Systems				
Sale and Marketing	Manufacturing	Finance	Accounting	Human Resources
5 Year sales trend Forecasting	5 Year Operation Plan	Year Budget Forecasting	Profit Planning	Manpower Planning
Management-Level Systems				
Sales Management	Inventory Control	Budget Control	Capital Investment Analysis	Relocation Analysis
Sales Region Analysis	Production Scheduling	Cost Analysis	Pricing/Profitability Analysis	Contract Cost Analysis
Knowledge-Level Systems				
Engineer Workstations		Graphics Workstations		Management Workstations
Work Processing		Document Imaging		Electronic Calendars
Operational-Level Systems				
Order Tracking and Order Processing	Machine Control Plant Scheduling and Material Movement Control	Securities Trading and Cash Management	Payroll, accounts Payables and Accounts Receivable	Compensation, Training & Development and Employee Record Keeping

To make a decision, you need to establish some basis. The criteria on which the decision is to be made need to be established and perform an analysis of the decision situation and make choice by weighing each decision option against the criteria. The decision criteria have non-probabilistic decision criteria and probabilistic decision criteria.

The non-probabilistic criteria do not take into account the probability associated with the outcomes. The criteria of non-probabilistic decision criteria is aimed at their failure to include important information about the chances of each outcome occurring. Some decision criteria take into account the probabilities associated with each outcome.

The certainty environment is predicated on the fact that the outcome from each alternative course of action is known. This makes choosing between the alternatives straightforward. But the typical business decision-making environment is uncertainty. Possible outcomes could be

specified for each alternative, but we will be uncertain about which outcome will occur (Groebner 2008).

In construction projects, the Building Code, Land and Design requested factor can be including by the certainty environment. Some jobsite uncertainty are listing here: Site condition change; Schedule Delay-Fabricator, Equipment, MEP; Labor Absence; OSHA penalty; Fabrication mistaken, like weld a rod plate; Material Missing or Short; Budget cut; Accident Damage. To treat with these certainty and uncertainty problems always are manager's big issue especially for those uncertainties. To make a decision, you need to establish some basis. The criteria on which the decision is to be made need to be established and perform an analysis of the decision situation and make the choice by weighing each decision option against the criteria. The decision criteria have non-probabilistic decision criteria and probabilistic decision criteria.

The non-probabilistic criteria do not take into account the probability associated with the outcomes. The criteria of non-probabilistic decision criteria is aimed at their failure to include important information about the chances of each outcome occurring. Some decision criteria take into account the probabilities associated with each outcome. This is probabilistic decision criteria. One of there is the expected-value criteria (Groebner 2008). The term expected value is often used in statistics to refer to the long-run average outcome for a given alternative.

Decision Making Generation

To make hard decision need data base and model base information sources, dialog generation and user windows. Figure 2-9 shows an example of the DSS generator for Dialog Generation and Management System (DGMS). It also works for BIM environment.

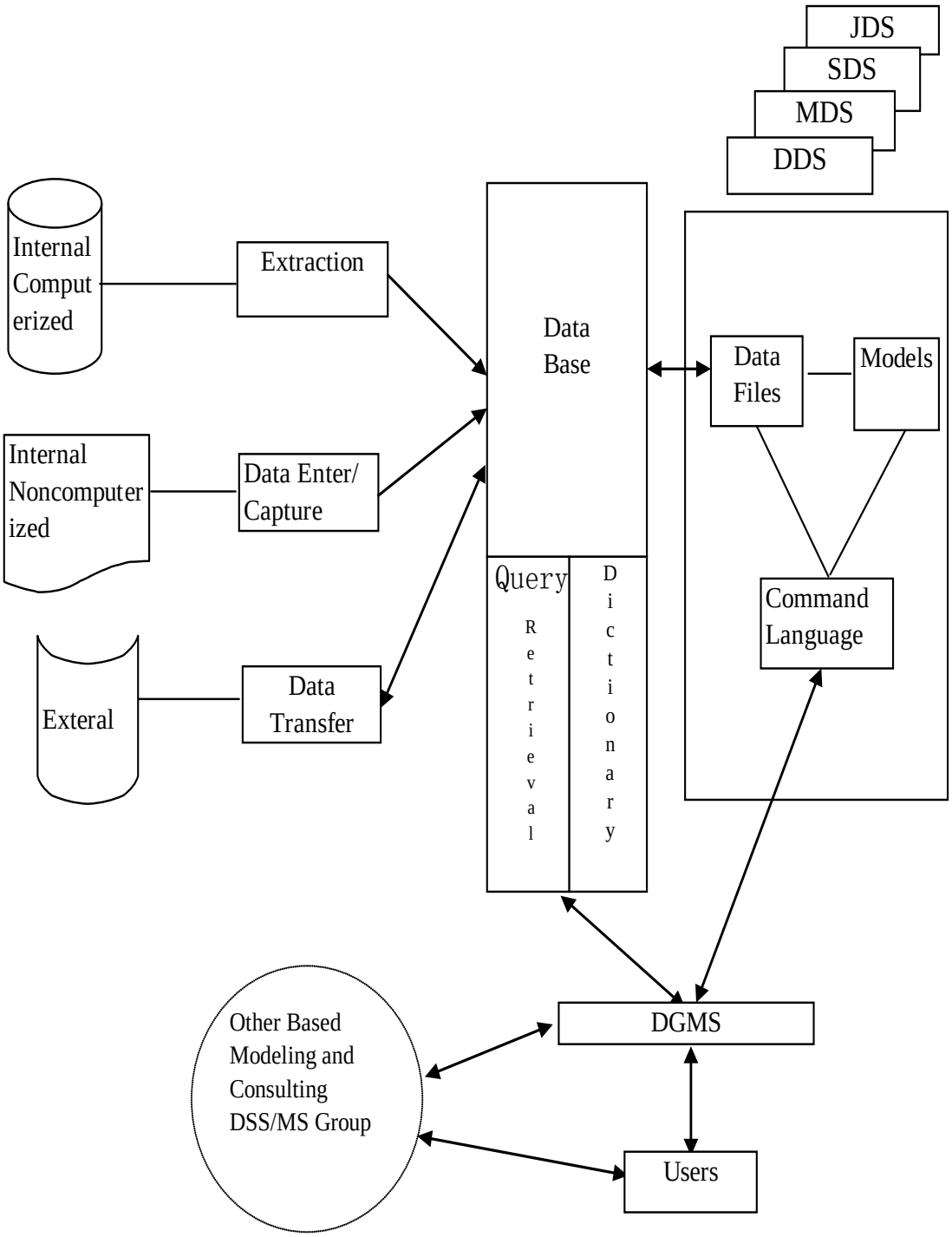


Figure 2-9. Configuration dialog generation management system of a DSS Generator (Sprague 1982)

In this case, types of systems for BIM under the generation system will be Design Decision System (DDS), Manufacture Decision System (MDS), Supply Decision System (SDS) and Jobsite Decision System (JDS).

Design Decision System (DDS) is a decision system to supply the designer. It may use designing system software that company already have or develop a new program model that based on company collected data system. BIM design model tools like Auto CAD, Revit Architecture, Revit MEP are using at BIM DDS.

Manufacture Decision System (MDS) is a decision system to help manufacture make decision. The Total Quality Control (TQC) and Computer Numerical Control (CNC) are such systems that current adopting at manufactures.

Supply Decision System (SDS) is a decision system for control supply chain. There are so much software like Plant Simulation (PS), Enterprise Resource Planning (ERP) and IBM Supply Chain Management (SCM).

Jobsite Decision System (JDS) is specific system which designed for jobsite decision. Most scheduling software has this function, like Primavera Project Planning. Expedition of Primavera is specific for JDS.

CHAPTER 3
METHODOLOGY

This study is going to address the synergistic combination of MSI and BIM to assist fabrication and erection in the construction of steel structures. This research is aimed at resolving the problems of fabrication in the shop and erection at the jobsite. The goal of the research is to analyze and to build a framework for the BIM decision-making model for fabrication and erection of steel structure construction. A detail sequence of fabrication and erection will be analyzed and tracked by using case studies comparing the traditional methods and BIM. The solution of each sub-problem involves the following steps:

1. Identify and describe the problem with requirements
2. Review related work
3. Propose evaluation method
4. Propose and implement approach
5. Assess approach
6. Show the contribution

Objective of Research

The objective of this research is to create a BIM decision-making model with the implementation in the erection of steel structures. It is a web-based system which is based on BIM, using manufacturing system integration (MSI) and other advanced project management methods. The proposed model can fit the needs of the steel structure erection demands. The combination of BIM and other systems will allow all the data from BIM to be integrated with effective MSI management. In this case, the site manager can send purchase orders to the manufacturing machines to make the parts they need. The integrated system can follow the same sequence to make steel pieces as requested for the project. Using this system, the biggest benefit is to avoid carrying forward mistakes through the entire process from manufacturing to erection. This approach also saves time in the material and documents delivery. It also helps in resolving problems at their first occurrence. In the proposed framework of the BIM and MSI system, the

intention is to synergistically combine the BIM system and the MSI system with the proposed framework. RFID is proposed to be implemented in the framework as the data management tool for data collection and integration. The framework of the synergistic system will be validated in the fabrication and erection process of the steel structure construction.

Modeling and Implementation

RFID (Radio-frequency identification) is a method of steel identification in the proposed research. This research suggests that RFID tags should be applied after the first step of fabrication when the major structural steel are cut and other minors (i.e. plates, angles, trusses) are fabricated. Scanner is used to scan all the pieces of the steel structure with RFID barcodes, at least for main columns and beam members. After the job is finished, each piece of information scanned will be translated into a serial code that represents the steel member. Then the data will be imported into the information system and the color of steel in the BIM model will be changed. This serial-code system is different from the bar-code system, which is used in fabrication and erection by some companies. The code system is not just a tracking code, but it is also part of the proposed system. It has a broader site management perspective, aimed at dealing with not only day-to-day but also item-to-item activities. This method can be used for all steel parts, even for plates and bolts. The code can be developed by adopting an existing bar code system or by creating a new standard to reflect workflow or supply chain.

Verification and Testing

Parts of this research are based on the ideas from other scientists and researchers. Most of the methodologies have not been tested or displayed. All of these give us more challenges in verifying the model and result. The first step is to perform a comprehensive literature review and gap analysis, and identify what is missing. Then, with emphasis on the jobsite sequencing, scheduling and cost controlling, the model will be validated by using the following procedures:

1. Discover related research and collecting the data.
2. Digest Web metadata. Put it in computer model.
3. Provide search and navigation services and estimate query complexity.

The result of each testing will be evaluated by the following methods:

1. Statistical report on collected metadata,
2. Real world usage using model-case studies.

This study selected two steel structure projects as examples to validate the system framework. Each case will be run through the system framework for results. In the case study, the data will be collected from project cost, scheduling and supervision. By comparing case study results from the two projects, the success of the research model will be verified.

Problems Release and Discussion

In the following discussion, the following questions will be answered:

1. What are the problems in steel design and fabrication?
2. What are the problems in steel erection?
3. What can this research do and improve upon?

To overcome the barrier, the key element is to use reference materials and first-hand documents to develop a project model just for the end users. The framework of the model need not be a full-size, universal model. But it could resolve questions and help in making decisions at least for one major construction division. To achieve this target, the following steps were followed:

The first step involved a comprehensive literature review and accumulation of data, tracking of progress, and monitoring the variables for two construction projects. This step also involved preparing simulation questions to test the model. The data from the selected construction projects were used as the basis for the proposed model.

The second step was to narrow down the major research scope. A large full-fledged model may offer inclusive functions and meet end users' needs, but it is beyond the scope of this study.

The third step was to study the existing models and compare them to the proposed model. The purpose of the comparison is to strengthen and improve the proposed model to become a more effective model. The adoption of some successful features and modules from these existing models can reduce the cost and time to build up the proposed model. During the study, some of the sample models found was used as reference in designing and developing the functions of the proposed model.

Finally, real construction project data was used to test the feasibility of the designed model. After building the proposed model, the real project data was used in the tests which produced the end results to simulate the project's jobsite performance. The testing process is shown in Figure 3-1. Three main factors measuring this solution process: Benefit Fit; Technique Fit and Safety Fit. If any of these three conditions not fit, the decision would not pass to become a solution. For multiple solutions, there are a process to innovation and combination each of them, then going to the final solution.

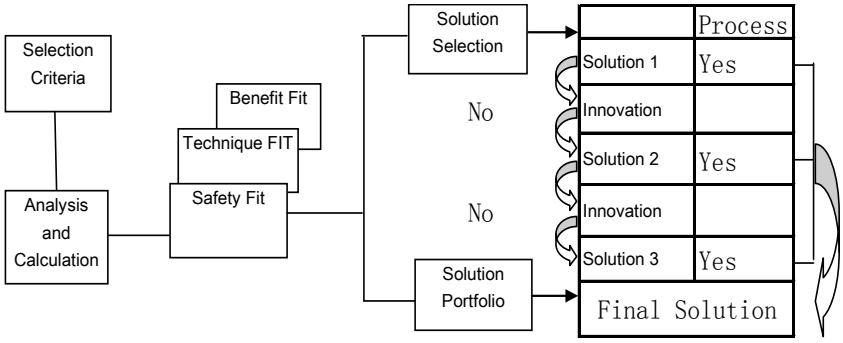


Figure 3-1. Model selections and solution process

Case Study Design

In general, steel construction can be divided into four continual processes: structural design, detailing and estimating, fabrication, and erection/installation (www.aisc.org 2009). Steel fabrication is one of the most important processes in structure steel construction. Most fabrication jobs are done in a shop. Then the fabricated steel is delivered to a jobsite. For large-

scale projects, steel fabrication may take much longer than the erection process. Steel Erection requires many detailed plans, trained skills, and special equipments and tools to finish it. Erection drawings show parts numbers and locations, connections, welding, drillings, and other details.

The erection schedule includes hoists and crane schedule, shipping schedule, and job planning. The main erection checklist includes: set up crane areas; work zones for each crane, or derrick; divisions for each derrick for shipping and sorting; every piece of steel erection and hauling arrangement; anchor bolts and embeds in footings; special equipment and tools rental and loading arrangement; power line and utility; special scaffolds, floats, needle beams and planks; securing of licenses, permits, and bonds; crews background check and job training; layout of electric power lines for hoists, welding equipment, compressors, hand tools, signal system, and lighting. Safety is an important issue in steel structure construction. The safety manager for the steel installation needs to check safety hooks, helmets and hard hats, safety belt, crane safety (space area, power line, load limits, etc.), welding and cutting, loading and hauling, weather issue protection, and fall protection.

In the case studies, the steps involved in steel construction were reflected, especially steel fabrication and erection. The framework of the proposed synergistic system shows the details in each step of fabrication and erection in steel construction. The details include: the major decisions to be made, the input variables, the project-specific constant, the related formulas and calculations, decision result, etc. Since all of the factors are project-specific, case studies will be designed to illustrate the functions of the framework of the system and to validate the framework of the system.

Contributions to the Construction Industry

This research proposes a model that combines web-based 4D, BIM, RFID and MSI techniques. The BIM/RFID framework focuses on site steel erection and organization. The program is based on a multi-purpose model, which uses RFID plus steel series-code and color-codes systems to differentiate between steel pieces, to help control the schedule of a project, and to describe the entire scope of construction. It relies on a 4D graphic scheduling to display real-time steel erection information. It helps with planning jobs, verifying erection information, controlling job sequence, site inspection, and other field related jobs.

The proposed BIM/RFID framework could be used in the life-cycle of a project. The significance of this BIM/RFID framework is that it helps minimize project mistakes. This framework deals with uncertainty problems, which is an area that needs a lot of investigation. If project managers can view the current project situation and predict the possible results in a virtual environment, it will be easy for them to control the changes. In addition, these project managers can find out solutions to deal with the possible mistakes or errors.

CHAPTER 4
BIM/RFID FRAMEWORK ANALYSIS

Decision Need for Typical Structure Project

In the Design Stage

In the design stage, architects are responsible for collecting, analyzing, and realizing the design intents of the construction project. Architects should maintain the documentations of projects and coordinate the related life safety and code compliance issues for construction projects. Architects also update documents and information in digital format, such as PDF, DWG, RVT or CAD (Hardin 2009). For BIM models, most software products support the functions to generate views from different perspectives. These views can be saved in different formats. At the design stage, project engineers focus on the project physical conditions. Using the proposed system as an example, since it has the framework for steel structure fabrication and erection, then if a project engineer uses the proposed system, their attention will focus on the physical conditions of the steel. In addition, the project engineer should consider the design requirements for other materials.

For example, steel structure design will be affected by the load requirements of the HVAC equipment, the lab equipment, and classroom equipment, etc. of a project. In this case, an architect needs to collect all the necessary information about the equipment and systems of the project. For a general contractor, if this is a design-build project, the general contractor will be involved in the cost engineering and will contribute their expertise and experience in helping with the design. For the case study used in this research, the steel fabricator (as a subcontractor) worked on the shop drawings and on detailing the steel parts of the structure.

The erector worked on the erection plan and the arrangement of the cranes; the protection of equipment; and the arrangements of the installation crew shifts. The crane supplier worked on

the weather analysis and forecast; in addition, the crane supplier was responsible for crane shipment, installation, and coordination plans.

Table 4-1. Decisions needed for a typical steel structure project

	Design need for typical steel structure project						
	Architect	Engineer	General Contractor	Subcontract (Fabricator)	Subcontract (Erector)	Subcontractor (Crane)	Subcontract (MEP)
Design	Design and specify the scope of work	Physical Condition and Material	Cost and Management	Shop Drawing and Detailing	Erection Plan and Arrangement	Weather and Crane Plan	Plan and Arrangement
Fabrication	Shop order, work flow	Detailing, Methods	Control and Drawing Submittal, Planning and Scheduling;	Sequence of Fabrication, Order Material, Sale or Keep; Steel Structure Adjustment According to MEP Equipment Requirement;	Erection Schedule and Plan Change, Welding Schedule	Layout Plan, Tie-Up plan	MEP Shop Drawings; Buy-out
Delivery	Delivery plan	Protection Plan for Special parts	Coordinate the steel delivery plan with other activities	Produce and adjust the fabrication of steel parts; coordinate the fabrication plan and delivery plan	Road selection; Prepare and start erection; Coordinate erection plan and delivery plan; pre-assemble	Weather; Safety; Crane plan adjustment	Finalize MEP delivery and installation schedules
Erection	Review Approve/Deny on-site project changes	Protection for Special parts	As-built drawings; coordination; monitoring schedules	Produce and adjust the fabrication of steel parts; coordinate the fabrication plan and erection plan	Site adjustment of the steel parts; safety control; quality control	Sequence; add/delete the number of cranes or workers; protection; safety	Coordinate work sequence with steel erection schedule; Welding Plan

The mechanical, electrical, and plumbing (MEP) subcontractors worked on their individual plans and arrangements. In the design stage, the information provided by the MEP subcontractors was used by the architects and engineers for calculation and design purposes. If the project physical conditions, such the space, soil conditions, or intended usage, do not allow certain types of MEP equipment or layout design to be used in the project, the MEP subcontractors would have to adjust their design drawings according to the project physical conditions.

For the design stage of the example project, steel structure design unarguably plays the most important role. The decisions made during the steel structure design affect other designs and should be done quickly and correctly. The following decisions need to be made to finish the design stage of the steel structure. All these questions are going to be included in the typical decision making modules in the proposed system as selection menus or dialog windows.

Architect's Decisions:

What type of standard structural system material(s) to use?

- Wood
- Steel
- Concrete
- Masonry
- Composite Construction
- Walls and the Building Envelope

What choices to make for the complex structural systems?

- Trusses
- Arches
- Rigid Frames
- Space Frames
- Folded Plates
- Thin-Shell Structures
- Stressed-Skin Structures
- Suspension Structures
- Inflatable Structures

Calculate or implement the following structural system selection criteria:

- Resistance to Loads
- Building Use and Function
- Integration with Other Building Systems
- Cost Influences
- Fire Resistance
- Construction Limitations
- Style
- Social and Cultural Influences

Engineer's Decisions:

Calculate loads on the building:

- Gravity Loads
- Dead Loads
- Live Loads
- Load Combinations
- Lateral Loads
- Wind
- Earthquake
- Miscellaneous Loads
- Dynamic Loads
- Temperature-Induced Loads
- Soil Loads
- Water
- Design decisions to make on beams and columns
- Design decisions to make on columns
- Design decisions to make on trusses and truss analysis
- Method of Joints
- Method of Sections
- Graphic Method
- Soil and Foundation
- Soil Properties
- Subsurface Exploration
- Soil Types and Bearing Capacities
- Water in Soil
- Soil Treatment
- Other Considerations
- Foundation Systems
- Spread Footings
- Pile Foundations
- Designing Footings
- Retaining Walls
- Types of Retaining Walls
- Forces on Retaining Walls
- Design Considerations
- Sample Decisions
- Design decisions on connections
- Wood Connections
- Species of Wood
- Type of Load
- Condition of Wood
- Service Conditions
- Fire-Retardant Treatment
- Angle of Load
- Critical Net Section

- Type of Shear
- Connector Spacing
- End and Edge Distances to Connectors
- Nails
- Screws
- Lag Screws
- Bolts
- Timber Connectors
- Miscellaneous Connection Hardware
- Steel Connections
- Bolts
- Welds
- Concrete Connections
- Rebar and Keyed Sections
- Weld Plates
- Shear Connectors
- Analysis of building code requirements on structural design
- Loading
- Allowable Stresses
- Construction Requirements
- Fireproofing
- Detailed design decisions for steel construction
- Properties of Structural Steel
- Types and Composition of Steel
- Shapes and Sizes of Structural Steel
- Allowable Stresses
- Steel Beams
- Lateral Support and Compact Sections
- Design for Bending
- Design for Shear
- Design for Deflection
- Steel Columns
- End Conditions
- Design for Axial Compression
- Built-Up Sections
- Open-Web Steel Joists
- Analysis of Wind Loading
- Analysis of lateral forces-Wind
- Design of Wind-Resisting Structures
- Analysis of lateral forces -Earthquakes
- Making selection from structural systems to resist lateral loads
- Bearing Wall Systems
- Building Frame Systems
- Moment-Resisting Frame Systems
- Dual Systems
- Horizontal Elements

- Building Configuration
- Torsion
- Plan Shape
- Elevation Design
- Analysis of Earthquake Loading
- Additional Considerations
- Overturning Moment
- Drift

For an engineer, the design and selection considerations are:

- Function
- Cost and Economy
- Shipping
- Acoustics
- Assembly and Erection
- Fire Protection

For an engineer, the technical considerations are:

- Connections
- Envelope Attachment
- Pounding
- Temperature Movement and Stresses
- Tolerances
- Stability
- Shop Drawing Review
- Construction Observation

General Contractor's Decisions:

Cost analysis about different sizes and types of steel materials that satisfy the architectural/engineering requirements.

Which steel type(s) is/are more cost-efficient in this project?

What is value engineering about possible options in steel design?

Fabricator's Decisions:

Do the shop drawings provide enough details for the steel structure?

What types of connections to use: bolts, welding, etc.?

Erector's Decisions:

How to install the steel structure?

How many crews need to be arranged for the installation of the steel structure?

Crane Operator's Decisions:

What weather will be expected during the installation of the steel structure?

How many cranes need to be arranged for the installation of the steel structure?

MEP Subcontractors' Decisions:

What information does the architect and the engineer need for their design of the steel structure?

What types or models of the MEP equipment should be used in the project?

What are the load requirements the MEP equipment has on the steel structure, including dead load and live load?

What are the room or space requirements the MEP equipment has on the steel structure?

In the Fabrication Stage

The architect will focus on the shop orders of the steel structure of the building. The architect will also work on the work flow of the steel structure, including design coordination and construction administration. The engineer will review the details of the steel structure and methods of pre-assembling and installation. The general contractor will work on the control of the construction administration. Before fabricator can start the production process, the general contractor should finish the shop drawing submittal, review, and architect/engineer-approval process.

The general contractor should also work on the planning and scheduling of the steel structure. The fabricator has to specify the scope of work and parts for shop work. The fabricator should communicate with the architect, the engineer and the general contractor is regarding to the structure steel connection and welding methods, sequence of fabrication, shop drawing submittal, and fabrication schedule and plan. For an erector in the fabrication stage, the

subcontractor will work on the erection schedule and coordinate the erection schedule with any changes on the steel structure design.

The erector will also work on a welding schedule to finalize the details of the steel structure installation. The crane operator will work on the layout plan of the cranes. The crane operator will also provide a tie-up plan for the sequence and coordinate multiple cranes. The MEP subcontractors will prepare the MEP shop drawings. The MEP subcontractors will also work on submission and review processes. The MEP subcontractors will decide on whether to perform their scopes of work by themselves or buy the service from outside.

In the case study, for the project in the steel structure fabrication stage, the decisions made involve a great amount of money and remarkable length of time duration. The following decisions need to be made to finish the fabrication stage of the steel structure:

Architect's Decisions:

Are the steel structure shop drawings correct?

Do the steel structure shop drawings coordinate with other shop drawings, such as MEP shop drawings?

Are the work flow and communication of the steel structure appropriate?

Are the design coordination and construction administration of the steel structure appropriate?

Engineer's Decisions:

Are the steel structure shop drawings correct?

Do the steel structure shop drawings coordinate with other shop drawings, such as MEP shop drawings?

Are the details of the steel structure shop drawings appropriate?

Are the methods used in fabrication, delivery, storage, installation, and inspection appropriate?

General Contractor's Decisions:

Has the shop drawing submittal, review, and architect/engineer-approval process been finished?

Can the submittal review and approval be finished before the start of the steel fabrication?

Has the scheduling of the steel structure been finished?

Has the cost arrangement of the steel fabrication been completed?

Has the steel materials been purchased and are in place?

When will the steel fabrication be finished?

Should the steel structure parts and assemblies be delivered all at once or in stages?

Have all the value engineering ideas been analyzed and discussed?

Fabricator's Decisions:

Have the reviews on shop drawing submittals been finished and approved?

Have the fabrication schedule and plan been completed?

Has the sequence of fabrication been finalized and followed?

Are all the steel materials for the fabrication ordered and in place?

If time is not allowed, should part or the entire fabrication job be sold out to the outside steel company or companies?

According to the MEP equipment requirements, has the steel structure adjustment been finished?

According to the availability of the steel materials, has the adjustment to the steel parts been finished?

In order to save the site-installation time, are there any other possible ways (different from the drawings) to fabricate the steel parts?

Are all the pre-assembled parts finished?

Erector's Decisions:

What is the sequence of the erection of the steel structure?

What is the sequence of the welding on the structure?

Crane Operator's Decisions:

Has the layout plan of the crane been finished?

Has the tie-up plan for the sequence and cooperation of the multiple cranes been finished?

MEP Subcontractors' Decisions:

Have the MEP shop drawings been prepared?

Have the MEP shop drawings been submitted?

What are the review decisions on the submittals?

Whether perform their scopes of work by themselves or buy the service from outside?

In the Delivery Stage

Delivery is the key of Supply Chain System. Time, route, and quality are three components of delivery. The decision making for delivery also focuses on right on time, right routes, and right quality service. The detailed delivery analysis focuses on space arrangement, loading efficiency, tractability, and safety in conveying.

For the example project in the steel delivery stage, the decisions made should cooperate with erection work and other trades. The following decisions need to be made to finish the delivery stage of the steel structure:

Architect's Decisions:

Has the review on the delivery plan been completed?

Engineer's Decisions:

Has the protection plan for the delivery of the special steel parts been reviewed and approved?

General Contractor's Decisions:

Has the delivery plan been reviewed?

Has the delivery plan been discussed with other relative subcontractors?

Has the site utilization plan been designed, discussed, and agreed by all the involved subcontractors?

Fabricator's Decisions:

Do the steel parts need to be adjusted?

Have all the steel parts been produced?

How to coordinate the fabrication plan and delivery plan?

Erector's Decisions:

Which roads to select as the delivery route?

Has the steel delivery been finished?

Has the preparation of the erection been finished?

Does the erection plan coordinate with delivery plan?

Do the steel parts need to be pre-assembled?

Crane Operator's Decisions:

What is the weather forecast for the next several weeks?

Has the safety procedures been analyzed and well-understood?

Does the crane plan need any adjustment?

MEP Subcontractors' Decisions:

Have the MEP delivery plans been finalized?

Have the installation schedules of MEP scopes of work been finalized?

In the Job Site Erection Stage

Jobsite uncertainty impacts the steel erection process and causes changed results in decision-making. Uncertainties include: schedule delay (fabricator, equipment, MEP or delivery), labor absence, OSHA penalty, fabrication mistaken, material missing or shortage, budget cut or drawing change, accident, or damage, etc. The architect in this stage is responsible for reviewing digital punch list and project closeout document for owners, engineers and contractors use.

For the example project in the steel erection stage, the decisions made affect the cost, duration, quality, and safety of the work and other trades. The following decisions need to be made to finish the erection/installation stage of the steel structure:

Architect's Decisions:

Have all the project change orders been reviewed?

Are the change orders approved or denied?

What are the influences of the change orders to the steel structure construction?

Engineer's Decisions:

What procedures should be taken to protect the special parts?

General Contractor's Decisions:

Have the as-built drawings been maintained?

How to coordinate the steel erection with other trades' work?

How to monitor and control the steel erection process?

Fabricator's Decisions:

If fabrication is in stages, how to produce and adjust the fabrication of steel parts with the installation requirements?

How to coordinate the fabrication plan with the erection plan?

Erector's Decisions:

Are site adjustments required on the steel parts? How to cut or fix the steel parts to fit the locations?

How to control the safety management on the jobsite?

How to control the quality of the steel structure installation?

Crane Operator's Decisions:

What is the sequence of the installation of the steel parts?

If one or more cranes are added or deleted from the site of the project, what will be the impacts on the time duration or cost of the work?

If one or more crews are added or deleted from the site of the project, what will be the impacts on the time duration or cost of the work?

How to protect the workers, the cranes, the surrounding materials and equipment, and other things existing on the site during erection?

How to implement the safety procedures?

MEP Subcontractors' Decisions:

How to coordinate work sequence with steel erection?

What are the requirements the MEP equipment has on the welding plan?

Components of the BIM/RFID Framework

In the proposed system, a BIM component has two information sources to support the decision making. One is database; the other is model base (See Figure 4-1). Each source gives BIM information and technique support. The proposed system will provide the following data for decision makers to make optimum decisions: (1) conceptualizations, such as a plan or financial support; (2) different decision-making processes and decision types, all involving activities for intelligence, design and choice; (3) a variety of memory aids; (4) a variety of styles, skills, and knowledge applied via direct, personal control.

The Decision Support System uses the corresponding IT language. There are also four functions in it: (1) representations; (2) operations for intelligence, design, and choice; (3) automated memory aids; (4) associate jobsite director. Intelligence, design, and choice are well-known paradigms which can help classify the operations used in decision making. (Sprague 1982) In the entire proposed synergistic system, the decision support system and the BIM system are integrated together. As shown in Figure 4-1, the proposed synergistic system in this research is composed of three modules: the database module, the Building Information Model module, and the model base module. In the database module, information can be extracted, captured, or manually entered from the information pool into the database of the synergistic system.

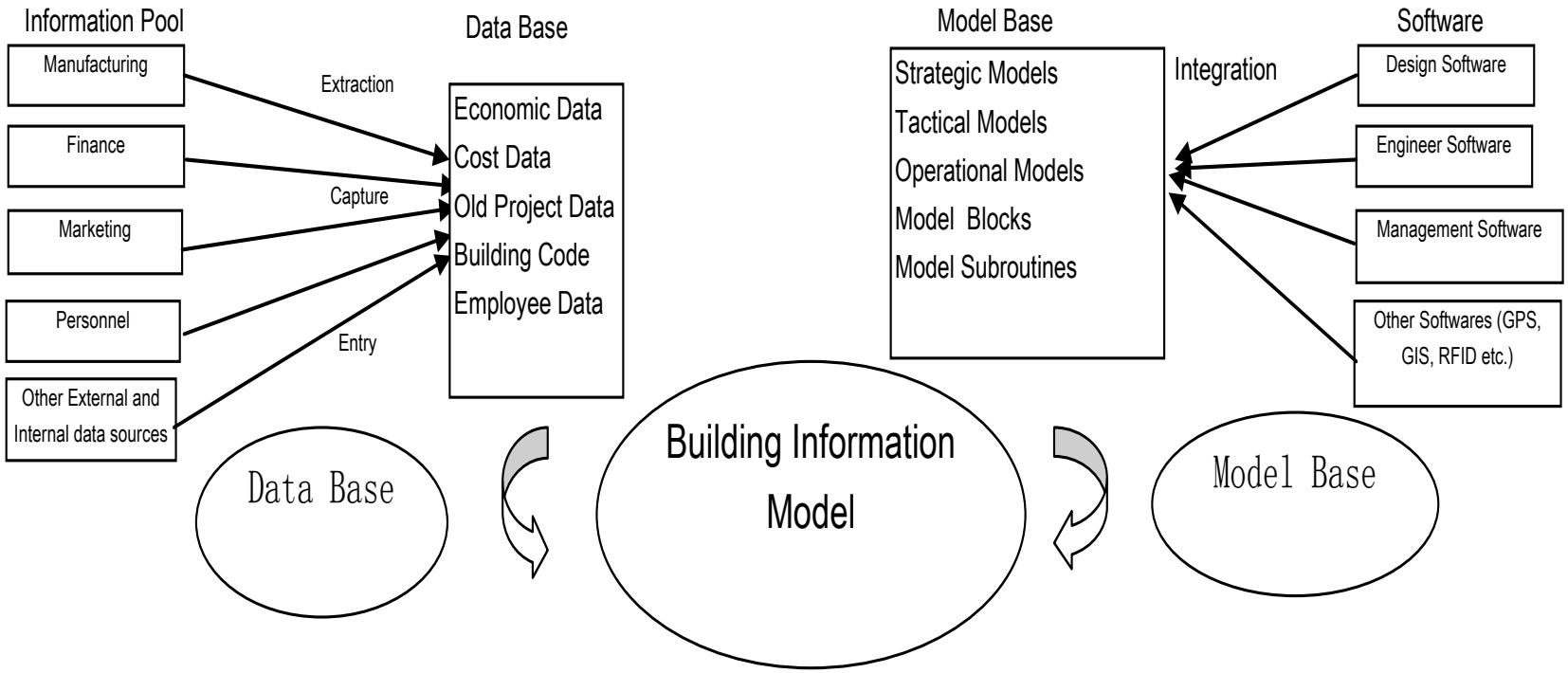


Figure 4-1. BIM and supporting bases

The information pool includes manufacturing database, company financial database, marketing database, personnel or human resource database, and other external and internal data sources. Here, the database includes the structured data and the data source includes the unstructured data. The databases or data sources in the information pool are not construction-project-specific. In order for the information to be construction-project-specific so that it can be used by the BIM model of a project, the information in the information pool needs to be processed and organized into the project database.

The project-specific database includes economic-trend data, cost data, project history data (which is the data from old similar projects), applicable building code, and project related employee data. After the needed information is pulled from the information pool, users can find the information from the BIM model. The BIM model is a web-based 3D/4D model. The BIM model is a combination of the web-based search engine and the visualization model.

For decision-making support purposes, the synergistic system needs to have the model base module. The model base module is composed of various model bases, such as strategic models, tactical models, operational models, model blocks, and model subroutines. These models in the model base is supported by the integration of different software, including but not limited to, design software, engineering software, management software, and GPS, GIS, and RFID, etc.

Computing and management modeling design have been improving the efficiency of the construction industry. Computer aided design software and project management software focus on different sequences and stages of construction. The software products help us achieve a paperless work environment.

Figure 4-2 shows the system relationship with decision making frame. BIM is a combination of all the project data which allows users to gather all the information they want to

know, including cost and schedule information. The goal of MSI is to bring together the component of subsystems into one system and to ensure that the subsystems function together as a system. In information technology, systems integration is the process of linking together different computing systems and software applications physically or functionally.

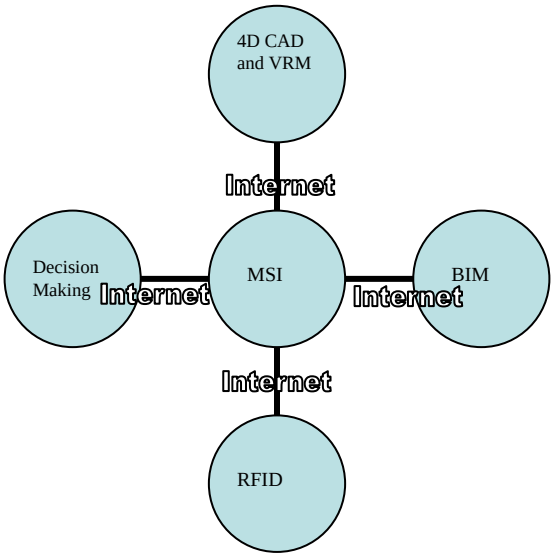


Figure 4-2. Systems relationship with decision making frame

Current MSI research addresses topics spanning over supply chain, system integration, metrology, simulation, ontologism, product data, green manufacturing, lean manufacturing, and sustainable manufacturing. All these are grouped under five categories: design and process, Enterprise systems, Manufacturing Simulation and Modeling, Manufacturing standards metrology, and system Integration for Manufacturing Applications. (http://www.nist.gov/mel/msid/)

Figure 4-3 shows how BIM is interrelated with all those three major performances of construction. Construction management includes management, scheduling and planning, and cost. The major research field between Scheduling and planning and Cost is supply chain management which works for short the time duration and save money. Cost control is the major

research field between Management and Cost. The most important part is the user model and decision between Management and Scheduling and planning.

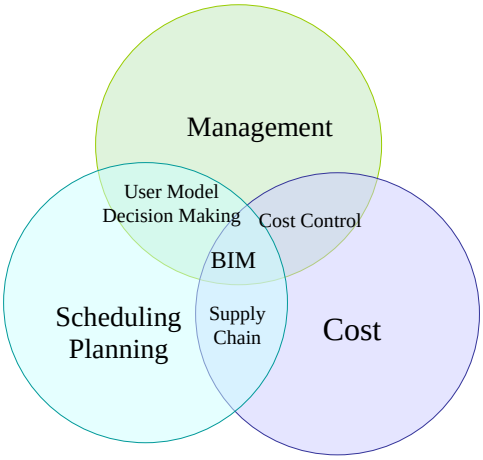


Figure 4-3. BIM functions in project management concept

BIM software was developed as a response to the need of information that can be shared, added to, altered, and distributed among the design team.

Primavera (www.primavera.com) and Microsoft Project are the most used construction scheduling software. Both of them are compatible with Navisworks TimeLiner. Any scheduling software that can produce an MPX or a Primavera version 5 file can have its static schedule linked to a BIM schedule through Navisworks. (Hardin 2009)

RFID Integration in the Proposed System

The significant contribution of RFID is the use of its data in tracking the structural steel member. The tracking distances are different when using different RFID tags. A passive tag has the similar distance as barcode.

It depends on reader's power that may extend to 20 feet at most. But the tag can reach up to a distance of 300 feet when using an active tag with battery. The code associated with each member is unique and stays forever if it is not changed. It keeps RFID exclusive and secure

when databases are safely used. The cost has become much cheaper as these production has been increased and the size of tags has also become much smaller.

The contribution of this research to the current state of RFID integration in steel structure construction has two parts: First, a usage model is created to link RFID data with BIM. This will improve its functions, such as data input, searching, sharing, and retrieve. (see Table 4-2) Then, the data can be used to develop a real-time 4D BIM jobsite management system. Currently, RFID in building construction are still focused on supply-chain and movement tracking.

BIM is an innovational model for the entire construction industry. It provides the tools for creating a paperless project environment and high level visualization imaging. But it is still a challenge to BIM users because BIM has not widely been acceptable by construction industry yet.

The following are the advantages of RFID:

- RFID has a tracking function to keep material together;
- RFID has memory function to keep material information anywhere;
- RFID can be easy carried and glued on material;
- RFID can be read by different readers and users;
- RFID can secure material safety by alerting a gate alarm system;
- RFID has been used successfully used for 20 more years;
- RFID has digital information which is easy to be transported and stored to a PC or a PDA;
- RFID has ample memory space which allows it to save as much as information as needed;
- RFID is an affordable technology.

RFID as a tracking technology has been widely used in many fields including some successful practices in construction projects. Few cases have been reported as using both RFID and BIM in construction projects. This is a new research field and has great potential.

The contributions that RFID can make in construction are:

- Help with BIM
- Help monitoring the Supply Chain
- Help the Fabricator – Piece build up
- Help the Erector –Identify/Locate Member
- Help the MEP contractor – Identify Piping and Pieces
- Help the Finisher – Find members and their Location

Table 4-2. Integration of RFID technology by steel frame building design and construction companies

Software	Main User	Advantages	Disadvantages	Using RFID
AutoCAD	Designer	It become universal design tool after more than 25 years (since 1982) develop and improve.	Professional software with a long learning time; imaging only without management function and detail connection	Show the corresponding Components
Takla Structure	Steel Designer, Fabricator Erector	A good BIM tool. Very good for steel and pre-cast concrete connection detail. It has 4D model supporting, schedule managing, Other model combination (IFC, DWG, DXF, DGN), report reference model information functions.	It has some design function but not better than AutoCAD and Revit. Less function in management stage when use it in general contractor office. No community function. Big cost.	Benefit all its software in detail information input and output. It can develop a real time 4D simulation or field implementation. Much more repot detail.
Revit Structure	Designer, Contractor and Subcontractor	Functional tools and easy to learn than AutoCAD for other background than Architecture. 3D model is good for BIM user. It has better section and elevation plan, quantities and Energy functions.	It has less detailing information for structure steel connection and MEP connection, without 4D function.	Benefit to its design components. It can develop more functions with information input and retrieve. Tracking members and more detail for quantities report.
Design Data (SDS/2)	Fabricator, Erector	Detailing system standard, automatically Design Connections, use framing plan approach to detailing	Not good for other stage works than steel structure detailing	Giving a possibility to share information with more users. Easy input and output data of components, developing a real time field tracking system
Vela system	Contractor, Subcontractor	BIM supporting. It has field safety control, scheduling, document sync, materials tracking, punch list and field report functions.	Less design and 3D functions. Material tracking software only records the report not a really tracking.	Improving it a better tracking and document sync function. Improving all its functions.

The other contribution of this research is to simulate a system that uses RFID and Geographical Positioning System (GPS) technology to achieve a real-time tracking of components and track building progress through the entire project. It includes a framework

designed to locate the column and beam members' positions and to track their progress in the construction process.

GPS technology has been used in transportation and survey activities for a long time. GPS technology has revolutionized many areas of people's lives; but it is simply too expensive to put a GPS receiver on every piece of material that is shipped. RFID electronic tags can be attached to almost all packages in shipment.

Unlike current bar coding systems, RFID electronic tags do not require a visual scan and can carry significantly more information. Currently bar coding is almost everywhere, but it requires a close and accurate visual scan by a bar code reader. It is simply too slow and often inaccurate. RFID tags, on the other hand, only require that the package be within radio frequency range of the RFID receiver or RFID interrogator. (Russell 2007)

On construction jobsites, GPS has just begun to be used on ground level and dump truck or equipment tracking. Using GPS and RFID, building components can be tracked from the moment they arrive on the jobsite to the moment when they are installed. Two technologies, RFID and GPS, can be used to locate steel column installation.

In this research, the author has developed the decision making model to improve the jobsite work efficiencies that use GPS and RFID technology. The model should have the functions for tracking materials and site layout and steel erection and allow for the use of GPS and RFID work for more erection sequences and different stages.

A case study involving a 1,230 Megawatt twin-unit-coal-power plant in northeastern United States illustrates the application of GPS and RFID technologies on a construction site. A large general contractor has implemented AutoID Technologies in a power plant construction

project to streamline the process of locating, verifying and delivering of pipe spools from large lay down yards to the construction site when needed during the construction sequence.

Prior to the implementation of the AutoID Technology the contractor estimated that it would take, on average, a two man pipe fitter crew one and half to three hours to locate, verify and flag pipe spools in the various lay down yards. After the implementation of the AutoID Technology the same crew was able to print out a map of the lay down yard or use a handheld device to find the exact location of the pipe spools every time. The new technology resulted in an estimated saving of roughly $3 million for the project. The general contractor has now begun using the technology to tag all structural steel components on the site and has plans to use the re-usable RFID tags, which have a life of 5 to 7 years, for other construction materials on this project and other future projects (http://www.atlasrfidsolutions.com 2008).

ENR (April 2008) had a example of RFID and AUTOID technique used on another US construction project, the 84,000seat Meadowlands stadium project in New Jersey. This $1 billion project, a just in time system, used GPS and RFID tracking for managing the delivery of 3,200 pre-cast concrete risers which were being manufactured off-site and assembled to form the bowl of the 84,000 seat stadium. From design to placement stages, the pre-cast concrete components were tracked using RFID.

It was estimated that project saving were $1million and that there was a gain of 10 days in the project schedule. This job was done by Skanska USA Building Inc. using software from Tekla Inc. and Vela Systems. The structure model was turned into a construction model by importing scheduling data from Primavera systems' P5 and using Autodesk's Navisworks to run clash detection (Sawyer 2008).

RFID and GPS on Site to Improve BIM Functions

The proposed system can be used as the location coordinates for the job site. It is associated with the methods such as laser equipment (i.e. Robotic Total Station) and Global Position System (GPS). The early laser equipment can emit a laser ray around the jobsite and a receiver can be used as the ground level. To install a steel structural member, four essential components are need in advance. They are the identified member, 3D position data, the party conducting the operation, and the connecting members (see Figure 4-4). RFID can measure identified member and serve connection data, GPS can measure 3D position data.

RFID data is the safe and durable solution for steel components. RFID tags are attached onto steel members giving a rough layout location of members. 3D position data is the location identification of the steel member. GPS receiver or tags are satellite measurement by Global Position System and it can make an accurate position point by its 3 segments: space, control and user. Laser based 3D solution also work to measure an accurate position.

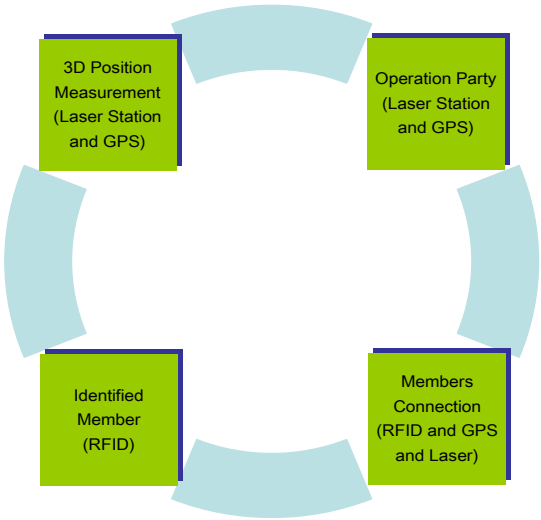


Figure 4-4. Steel erection components

The party conducting the operation includes the crane operator and equipment. A crane GPS solution can link the 3D position data and with the party conducting the operation in a

single system. The RFID and GPS all can be read from a mobile reader (RFID) or control sensor box (GPS) installed in the crane operator cabin. RFID system and GPS system can work well at the same long wave radio frequencies between 285 kHz and 325 kHz. These frequencies are commonly used for marine radio, and are broadcast near major waterways and harbors.

The connecting members information consists of other members' 3D position data so that the connector can use the right bolts or level welding plate on the right position to install the member at the correct angle. As-built checking is one function of laser station. This function can be used for column splice connection checking as well. An example will be used to explain how this RFID data when associated with laser station and GPS can help in steel installation and in checking the erection plan.

RFID data arrives on the jobsite after fabrication. The steel components with GPS and RFID tags are tracked after leaving the fabricator's storage. A just-on-time system arranges the arrival time and crane operation plan. The site GPS equipment begins to work on the location survey of each component based on the RFID data sent from fabricator's PC. The azimuth data will be recorded by each RFID sequence.

A truck enters the gate with an RFID reader on it. At the same time, a crane begins to hoist the members according to the erection plan sequence. The crane operator looks at the GPS and RFID data in the 3D control box. Then the operator follows the order to move the first column to its GPS position (see Figure 4-5).

It shows the time for the first column to be set on the base plate. The GPS system helps the operator to adjust the column position while the 3D-laser-station as-built system is checking its vertical and horizontal level to make sure that the column has been installed according to plan. After the first column stands up, a GPS sensor will be attached onto it as a reference GPS point.

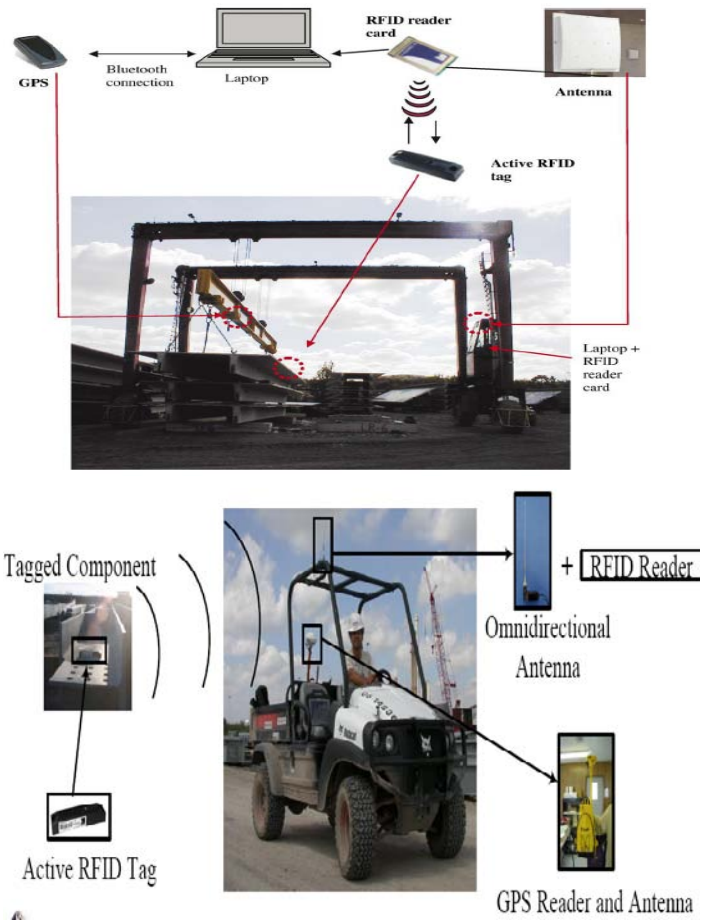


Figure 4-5. Examples of RFID and GPS use in steel structure erection (Ergen 2006)

The rest of the steel components are erected by using the same methods. GPS transmitters are used to help the operator measure the positions of components. They are all built up by using RFID data so that the exact locations of the connecting members are known. The RFID tags are collected for reuse and their data were transferred into a 4D model.

In this example, sequence one is going to finish all works and sequence two has just finished columns. The welding connecter is reading the last beam's RFID data by PDA. It says this beam has a 3/4" fillet weld connection with column RFID# 1C10 and a shear plate - PL1030's location (GPS #3) on outside face for support of beam RFID # 2B30. The connecter uses GPS data receiver to find the PL1030's mark and weld it. The deck foreman is working on

GPS equipment and data to measure the beam and girders' level, using RFID data to arrange the layout process and orders.

A plumbing foreman uses Robot MEP Station to measure the plumbing level and set hangers as specified by the RFID data. Then he uses GPS for the piping hose connection and sink's location on the floor. In the 84,000 seat Meadowlands, NJ stadium project. This $1 billion project had a just-in-time system, which used GPS and RFID tracking system. The project had deliveries of 3,200 pre-cast concrete risers manufactured and assembled to form the bowl of the 84,000 seat stadium. From design to placement stages, the pre-cast concrete components were tracked by RFID (ENR 2008).

CHAPTER 5
BIM/RFID FRAMEWORK IMPLEMENTATION

In this chapter, the author may discuss in detail about the decision framework of integrating RFID with BIM models. Figure 5-1 is a flowchart of RFID Data Implementation. Based on the flowchart, the methodology for using RFID technology for structural steel components, such as a steel beam or column, will be discussed. The use of RFID in the BIM system will also be discussed, in addition to how the decision support systems will transmit data read from RFID, retrieve the requested information, integrate the information in analysis process, and update the BIM project model when a decision is reached. In this chapter, the erection of a steel beam is used as an example in order to show:

- How the details about structural components are stored in RFID database in the chip memory
- What meta-data or types of data need to be stored in the chip memory in each step of steel construction
- What meta-data or type of data need to be stored in BIM database in each step of steel construction
- How the RFID data is read from the chip memory to BIM database via wireless Internet in each step of steel construction
- How the decision making or support systems can use the information retrieved from the RFID database for analysis, simulation, calculation, and selection of useful data

The construction jobsite has many uncertain conditions and risks. For example, site condition change (ground sink, flooding, weather change); schedule delay (caused by Fabricator, Equipment, or MEP); labor absence; local or OSHA penalty; fabrication mistake; heavy equipment loss by theft; material missing; budget cuts; unexpected damage; etc.

It is difficult to claim that a result proposed by the system is the best one or most suitable to the project conditions. But it is possible and feasible for the system to generate a result which will satisfy the complicated criteria of the evaluation module of the system. The suggested result

would have great potential of saving construction time, decrease cost, improve safety record, or achieve better quality in the end of the construction process. In this chapter, the author will use a steel beam component as an example and show the logic behind all the information retrieval and updating process.

In the steel structure erection process, there are many factors or variables affecting job performance. The variables in the process include: time, cost, quality, safety procedures, building code, workers experience, etc. Different projects have different weights associated with these variables. For example, in a time-critical project, the time issue will be the most important factor, and hence will have the most weight. For a power plant construction project, safety will be the most important one in all the variables.

Generally, steel construction is a complex manufacture-delivery-installation process with great probability of failures or errors. The time, cost, and safety (Building Code and OSHA regulation) are always the first three considerations for a project. Those three factors can also be used to evaluate a project's performance and quality.

BIM/RFID Framework Description

BIM users identify local solutions and provide a richer, more specific design at the early stage. This requires more thought and effort (expertise) than what is required when professionals design projects using typical 2D standard practices. However, it leads to higher quality designs through more detailed consideration of alternatives, and drastically reduces the effort required for production detailing and preparation of shop drawings. (Sacks 2008)

The decision making model uses BIM and RFID data on the erection status of steel members to identify solutions and reduce the conflicting information derived from different drawings. Existing BIM tools have functions to satisfy project requirements, such as estimating and scheduling. BIM is strong at designing and weak at project control and decision making.

In a test of BIM tools by the Eastman group for BIM exchange standards for IFCs, they found a broad spectrum of capabilities and limitations in BIM. In most cases, almost all of the geometry was transmitted, with local specific errors that could be corrected. However, the piece count of the model changed. Importantly, all of the exchanges in that example allowed only static, non-editable geometry exchange; editing on the receiving application required re-building of the pieces. There was also a wide variety of mappings between internal model objects and the IFC objects used to represent those (Sacks 2008).

At least part of these problems can be solved by using RFID data in conjunction with BIM. RFID is not only a good identification tool, but also a data storage tool with a limited size of memory. Most construction materials can be identified by using RFID tags. Figure 5-1 shows how RFID can be used in BIM for component tracking. RFID attached to each construction material and represent them in the BIM model for construction process.

RFID works for all BIM components. One single and unique set of identification codes is used throughout the BIM model of a project. This marked identification helps in tracking the building components and makes using the BIM model to do that easier.

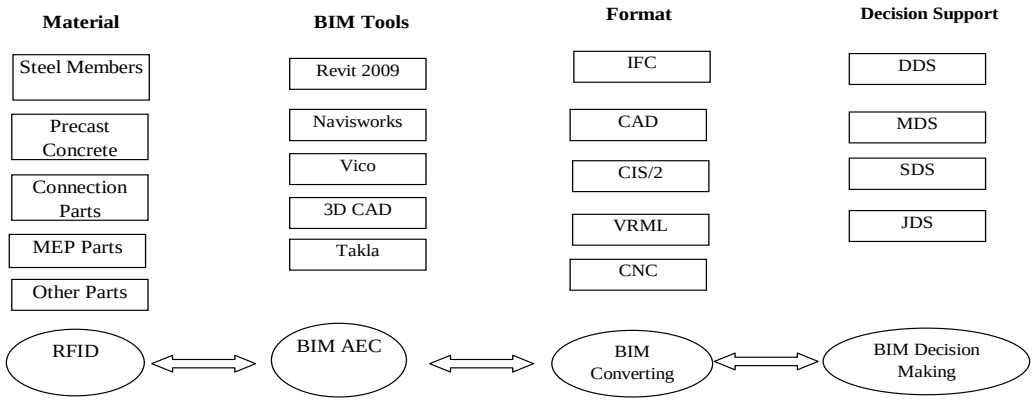


Figure 5-1. RFID used for BIM components

Steel fabricators use different identification methods for steel members. Sometimes fabricators use their traditional ways to identify steel members. For example, W12X40 is a marker of column/beam wide-flange shape steel. On a project, wide-flange steel is commonly selected for structural uses. When a user searches for steel components and enters W12x40, BIM tools, such as Revit and Navisworks, will show all the same members that are used in the project and be able to show them in the 3D image view. W12x40 are only symbols for these members. In BIM tools, W12x40 column at the spot of C3 (the intersection of column line C and column line 3) has no difference with the W12x40 column at the spot of B2 (the intersection of column B and column line 2). RFID technology helps to distinguish the W12x40 members individually. In this sense, RFID enriches and completes the information available for steel members. Each W12x40 steel member is differentiated by its location, date and shop of made, connection features, and so on. In this case, each member has a special serial number as its ID and is saved in its RFID tag's memory.

To link with the system to a jobsite or an AEC office need a cable network or wireless transmitter is needed to transfer RFID information to a central database. On-Line Analytical Processing (OLAP) can be used for essential business applications (including sales and marketing analysis, planning, budgeting, etc.). Unlike typical end-user applications, OLAP products are regularly called upon to process large amounts of periodically refreshed data. Figure 5-2 (Xie 2005) shows the process of external data connection to an OLAP system. A web-based information system gives OLAP widely operation field. The contribution of OLAP in this research is in the calculation process when using model for decision making.

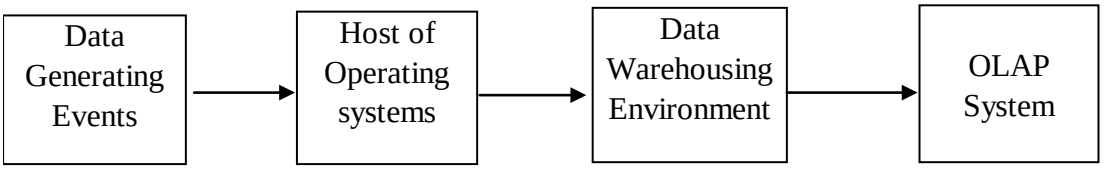


Figure 5-2. Process of external data connection to an OLAP system (Xie 2005)

BIM/RFID Framework Components and Relationship

Chapter four discussed the detailed composition of the proposed synergistic BIM and RFID system. The synergistic system is built on the existing software systems. Figure 5-3 shows the proposed synergistic BIM/RFID framework, which is supported by three main components: Manufacture Information System (MIS), Web-Base BIM Control System (WBCS), and Decision Support System (DSS).

BIM testing is a functional block that includes Mathematics, Statistic and other methods, to check data usability and decision feasibility. The Decision Tree is a very useful method to help managers making decisions. Much software has it in functions, like ILOG CPLEX**,** TreeAge, @Risk, DPL 7 and Microsoft Dynamics. These modules have digital results to serve the next level information system modules, such as Design Decision System (DDS), Manufacture Decision System (MDS), Supply Decision System (SDS) and Jobsite Decision System (JDS). Refreshed data after testing and OLAP processing are output to model based decision supporting systems. In this sequence, the BIM/RFID framework is tested and data results are ready to be used to make the optimized decision.

MSI integrates the information and simulation systems to develop an operational BIM environment. The systems integrates the supply chain system product data and sustainable manufacture, VRML or other simulation tools, BIM 4D model (such as NavisWorks and Vico), on-line analytical processing, and decision tree and other decision software.

The web-based 4D BIM control system integrates the supply chain system product data and sustainable manufacture, BIM 4D model (such as NavisWorks and Vico), on-line analytical processing, real time jobsite control system, and decision tree and other decision software. The decision support system (DDS, MDS, SDS, and JDS) integrates on-line analytical processing, real time jobsite control system, and decision tree and other decision support software.

All these real time jobsite control system, decision tree and other decision software, etc. in the third layer is the middle-ware between the proposed synergistic system and the basic data collecting and organizing tools and systems.

The bottom layer of Figure 5-3 shows the basic data collecting and organizing tools and systems. These technical tools include building code and safety regulations, BIM 3D files (such as AutoCAD 3D, Revit, NavisWorks, CIS/2), Project Scheduling Files (such as Microsoft Project or Primavera files), Web-based PDA communication technique, and GPS, RFID and other laser identification technique. The lines between the third layer and the bottom layer indicate the relationships between the middle-ware systems and the project-specific files and data.

The Process of BIM Implementation

Brad Hardin is a founding partner of BIM consulting firm-Virtual Construct Lab. He noted that in any organization a BIM team usually has to follow ten critical steps to be successful in the implementation of BIM (Hardin 2009):

Step 1: Identify a BIM Manager
Step 2: Develop an Estimate of Cost and Time to Implement and Use BIM Software
Step 3: Develop an Integration Plan
Step 4: Start Small
Step 5: Keep the Manager Trained
Step 6: Support the Manager by Starting a Department
Step 7: Stick to the Plan but Remain Flexible
Step 8: Create Resources
Step 9: Analyze Implementation
Step 10: Monitor New Software Proposals and Industry Trends

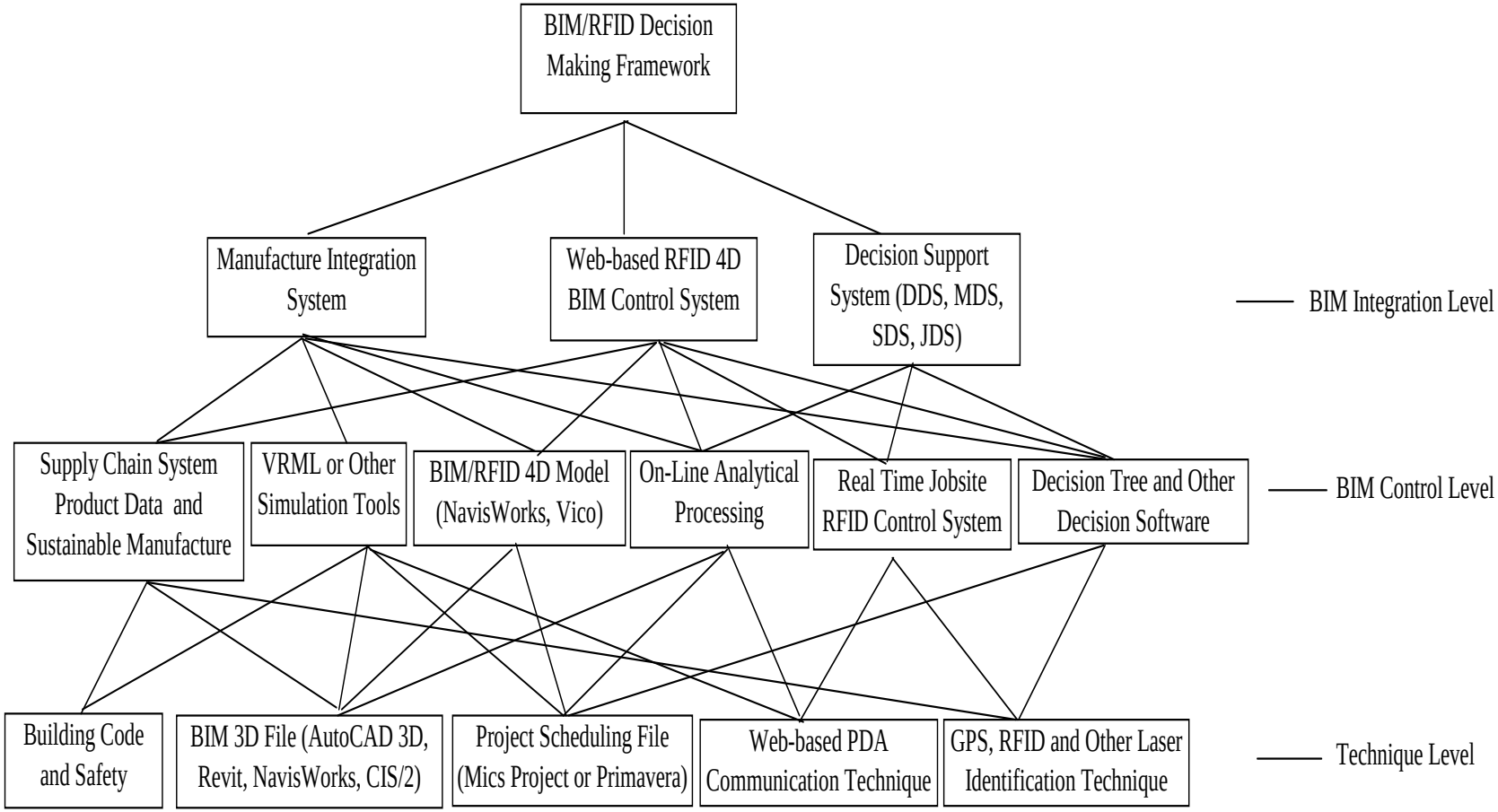


Figure 5-3. BIM/RFID framework components and relationship

The ten progress steps are very good for enterprises transforming from traditional workflow to a BIM workflow. Steel structure construction is similar to most other manufacturing industries. It has a special and standard erection workflow.

Figure 5-4 shows a traditional erection flow chart for structural steel. In this workflow chart, the actions are what users do in a normal traditional process for steel erection. BIM changes traditional erection methods.

BIM tools are suitable for every construction process covering from erection plan to sequence management, from estimating and scheduling to site monitoring and inspection. In every project, some exceptional changes may happen. With few exceptions, there is no unchanged schedule or on-time project delivery in construction projects. So it would be impossible to make a universal decision model that works for any construction projects in whatever stages or applicable to any RFI and RFC actions.

To create a useful framework of decision making process and to analyze factors of the process can help BIM users to make decisions. The process and factors show the relationships and functions of AEC members and they can make easy decisions with the help from a transaction of BIM decision tools. To follow this erection work flow, BIM works with different needs of the workflow actions.

For example, a crane on site is an action that connects with erection, crane and safety plans. The BIM/RFID decisions making process is in determining how the manager can arrange the crane on time, whether or not the weather is acceptable, whether the crane is in a safe position, whether the project has the right number of machines and whether cost is affordable.

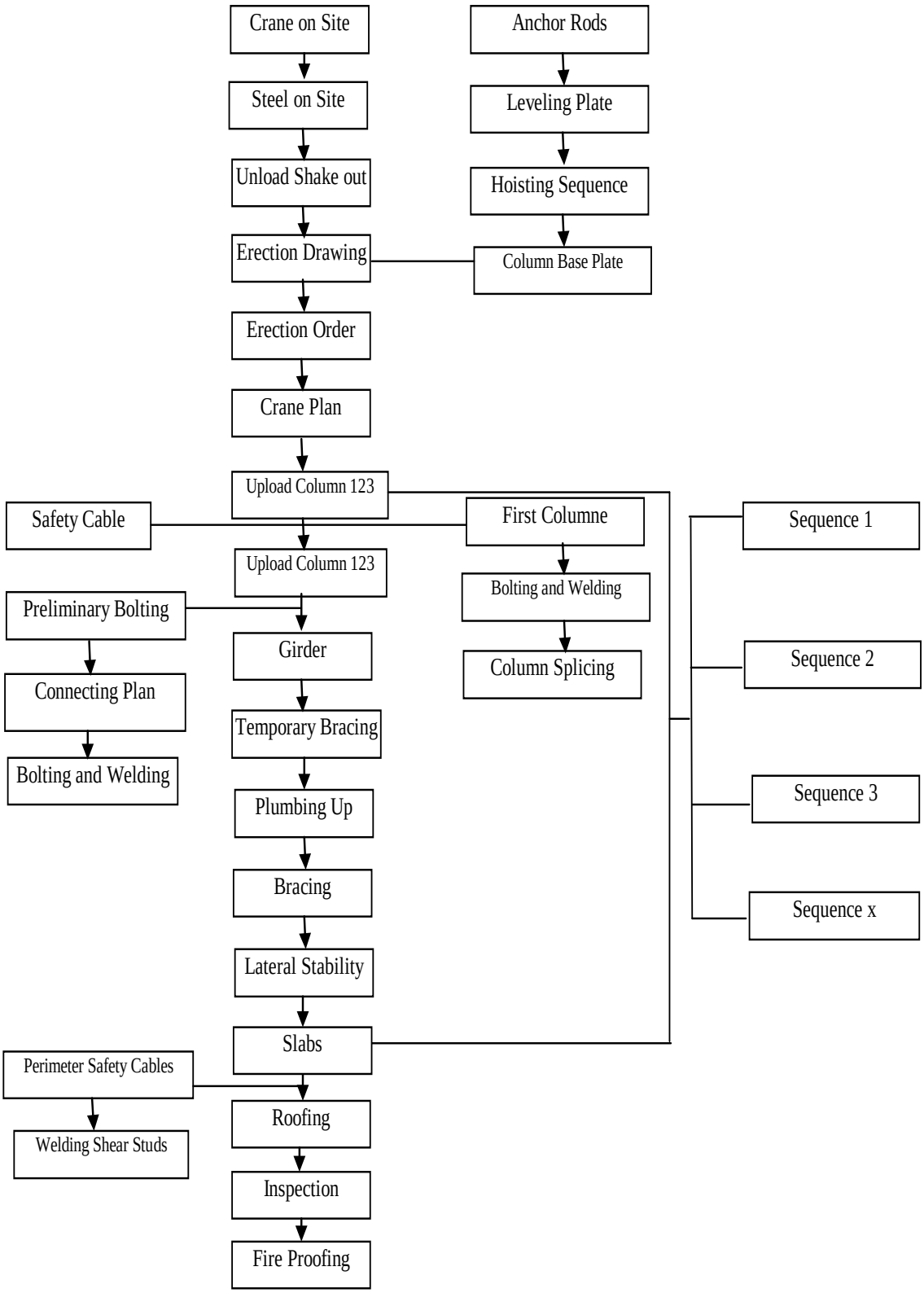


Figure 5-4. Traditional erection flow chart

BIM/RFID Framework

As shown in Figure 5-5, the BIM/RFID Framework has three parts: Data Base, Testing Center, and Model Base. The three parts are integrated together and provide analysis, calculations, simulations, or even decision tree results for users to make optimized decisions. To illustrate the use of the synergistic system described in Figure 5-5, the whole process of a user starting from the intention to look for a decision and ending up with an optimized decision made is discussed.

The process is a cycle. Each step of the decision-making process is saved in the appropriate database. When a decision is reached, the resulting decision can also be saved in the database of the BIM/RFID framework as indicated by the dashed arrow in Figure 5-5.

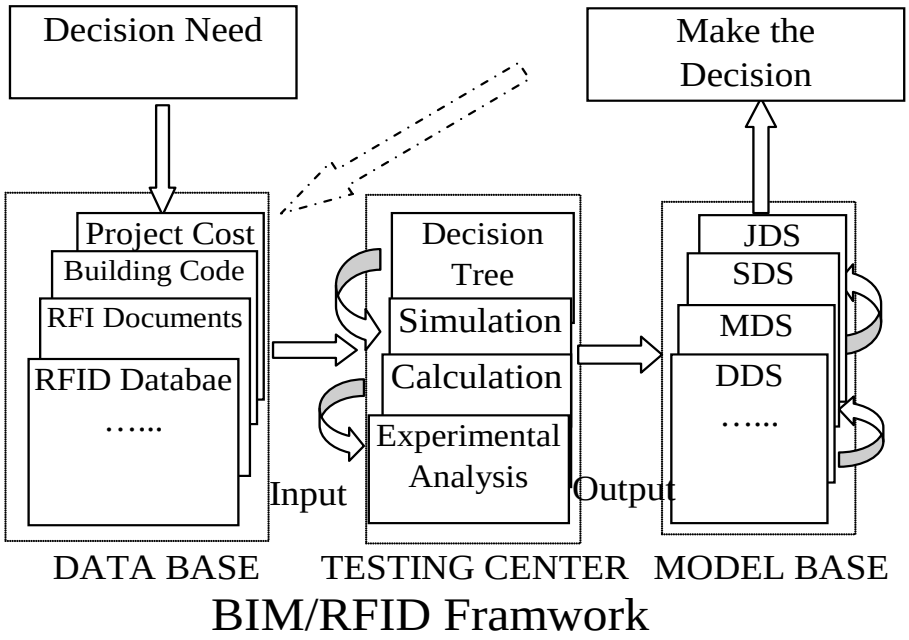


Figure 5-5. BIM/RFID Framework architecture

BIM Data Base

The database of the BIM/RFID Framework proposed in this research is not limited to one single data format. The data format could be MS Excel data for project cost or budget or it could

be text data, word file, or Adobe PDF format for building codes. It could be in an Oracle database for employee data or it could be in HTML format for marketing information.

Usually, there is no connection between the databases of BIM/RFID Framework including all information and data collected from past projects, building administration, supplier, market, etc. When a user of the BIM/RFID Framework system needs to make a decision, they will first go to the related databases and retrieve the data needed.

BIM Testing

After the needed data are collected from various databases, they will be sent to the testing part of the system. The testing center is a function block having the intelligent and automatic transacting function. It can use intelligent decision information system. It also serves as center for information collection, calculation, analysis and simulation. One or multiple testing methods can be used. During the decision-making process, decision support systems may request more databases than the ones already selected and opened by the user before.

BIM Model Base

In Figure 5-5, when the decision is made, it will be processed by the related software products to either demonstrate the changes or take actions. Decision support systems of BIM/RFID framework includes: Design Decision System (DDS), Manufacture Decision System (MDS), Supply Decision System (SDS) and Jobsite Decision System (JDS). Examples of DDS include AutoCAD, Revit, Micro Station, etc. When the design is eventually decided to be changed, the change will be made to the BIM project or other DDS files.

After the design change is finalized in the BIM project model or other DDS files, the change is recorded in the system. That marks the end of making decisions. Then the BIM/RFID Decision Making system can be used again to answer other questions.

Figure 5-6 shows the BIM/RFID network and the relationships between the MSI, decision making model and BIM components. The main function of the MSI is to assist the BIM/RFID system with decision making.

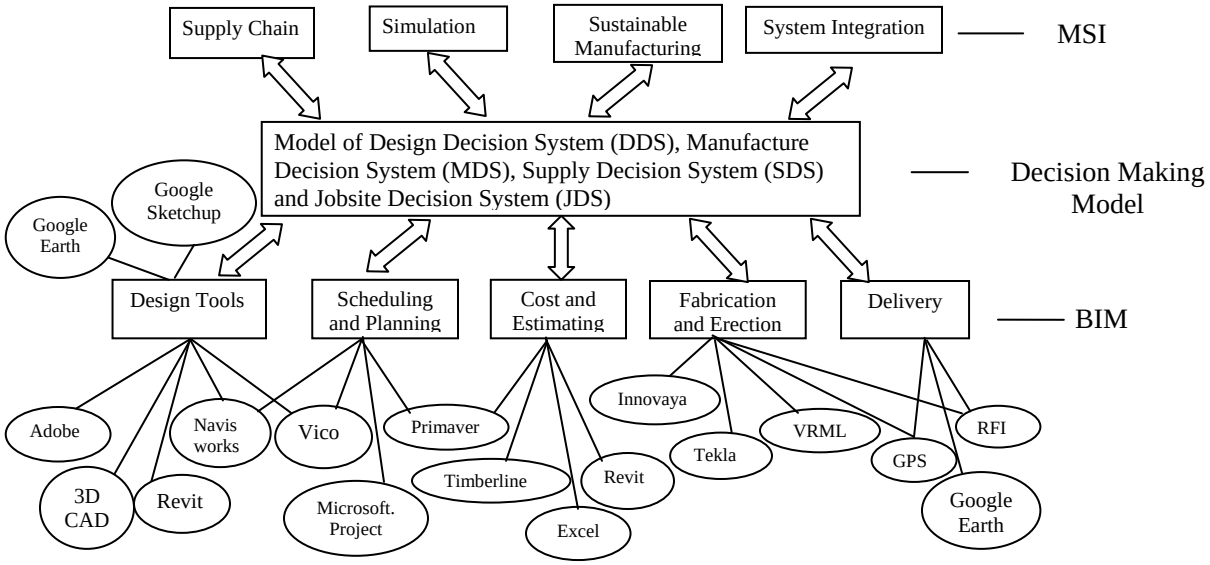


Figure 5-6. BIM/RFID Framework network

BIM/RFID Framework Implementation for Steel Structure Project

Knowledgeable BIM Team

A knowledgeable BIM team is the key requirement for successful use of the BIM/RFID Framework. First of all, BIM team members should know and be skillful with at least one BIM tool. They should be familiar with construction processes. Previously in this Chapter, the ten steps to successfully implementing BIM were listed and they should be followed.

Using RFID in the BIM/RFID Framework

From above research and analysis to RFID, the BIM/RFID Framework will use RFID to assist with its advanced functions in member verification and information tracking. The implementation of RFID in steel structure construction can improve construction quality and save time and cost.

Design Decision System (DDS) is a system that supports a designer to make a design decision. All design features can be represented by RFID layers. The material feature layer includes information such as loading, tension, heat resistant condition, and bending features of materials. Some layer names are self-explanatory, including: weather layer and material layout location layer. Police layer includes information such as OSHA regulation and building code. Design feature layer includes information such as building type, design style, and zoning information.

Supply chain layer has information such as traffic information, weather, road condition, and deliver information. Cost layer stores the estimating of different layers cost. There are other layers for sequences of projects. All these layers as BIM components can be used to make decisions on design, manufacture, supply, and installation. They can help in simulating building process and building up a building structure immediately if the cooperation information were given. In the near future, RFID could be combined with construction robots.

Figure 5-7 shows the RFID using data flow for BIM/RFID Framework decision making process. These data can be used without testing module because they are mature data which had been acceptable for the user. But those changeable and uncertain data still need to be tested by BIM/RFID testing systems. RFID database has many data layers, such as RFID design data, material data, location data, and supplies data. After selecting and retrieving by different needs, selected data input to BIM model base to run out a result. The result imply at BIM decision making process to practice the decision. The final solution as finished RFID data saves back to RFID database for future decision making using.

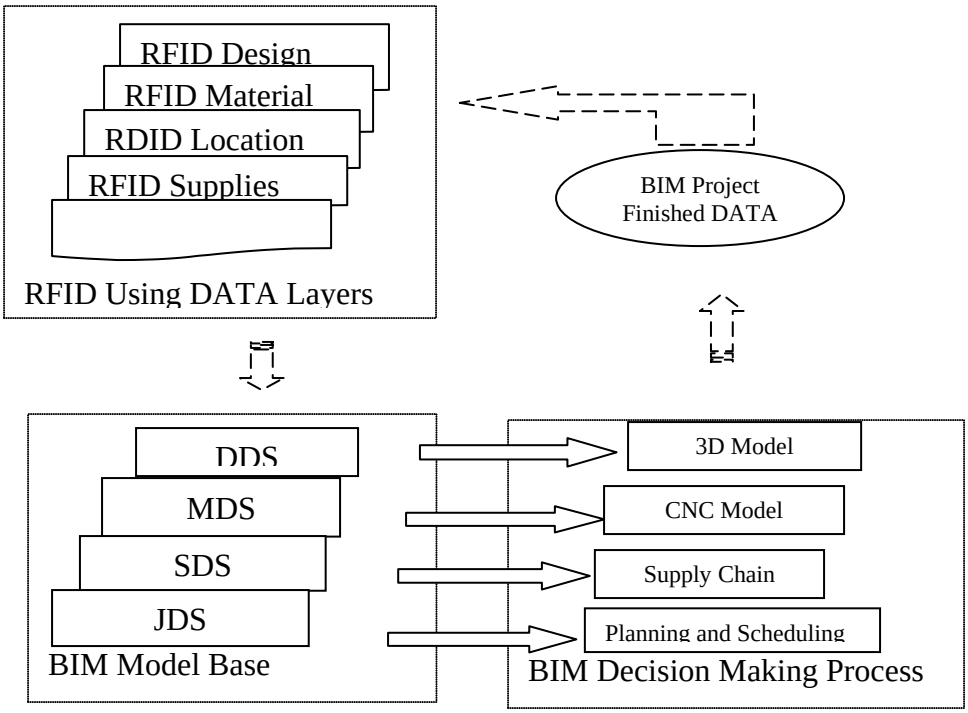


Figure 5-7. RFID using Data flow for BIM/RFID Framework decision making process

Using RFID for Steel Structure Design

Using RFID technology for construction parts marking and tracking has been widely accepted. The use of RFID as a series number is one of the basic functions of RFID. RFID can be used as a standard measurement to identify steel design components. For example, the steel grades on BS5959 (AISC) for steel tension design have specific design requirements based on different members' thickness and temperature. When designed at a structure's external temperature to minimum -15°C degree, the incorporated RFID tags will automatically show that the maximum thickness for a Grade 50A Beam is 10mm (Hayward 1989). If a user entered this data in the Design Decision Support system (DDS) and RFID tags, when erecting members at a jobsite, it would give a warning when somebody installs a wrong piece, even if that piece fits to be connected with other parts.

RFID can be coordinated with the standard design data so that designers can easily find the right piece from a data pool. In another words, users can read the information even from RFID

series number, for example, RFID number BS4360-WR50-W12x36 is a BS 4360 Grade, weather resistant high tensile wide range steel 12 inch wide and 36 pounds weight steel member. For the 10mm Grade 50A Beam example as described above, the next time if all conditions are the same, if a user gives the order to the DDS, the fitted RFID members will be selected.

The selected item fits to the required field-beams, columns and girders. Then the steel members for a wall, a floor and a building will be automatically verified by using RFID tags on the members and the system functions of the BIM/RFID decision support system. RFID using data layers can be used as design components to create a 3D model.

How the RFID Works in a Steel Structure

The details about structural steel components are stored in the RFID database. Depending on the technology limitation and chip cost, the memory in the chip can reach 256 kb currently. This memory can be written to with only minor information to show steel members' IDs and location information. But users can still retrieve other information from RFID system when using the wireless technology and ID coding system (For details see Figure 5-8).

The RFID system uses a Universal Product Code (UPC) which was developed for groceries from mid 1970s. The UPC code is the same coding like barcode system which is still widely used today. Currently, the RFID system had been installed to expedite non-line-of-sight data capture using RF to read the electronic product code (EPC) on RFID tags. The RF domains such as cellular telephony and wireless LANs are accustomed to working at much higher power levels.

There are more host processing capabilities in cell phones than are present in tiny RFID tags as of the first EPC GenII/ISO 18000-6c RFID infrastructure (free up the 860-960 MHz UHF spectrum, similar to IEEE 802.11 WiFi protocols for unlicensed RF data communications). (Miles 2008)

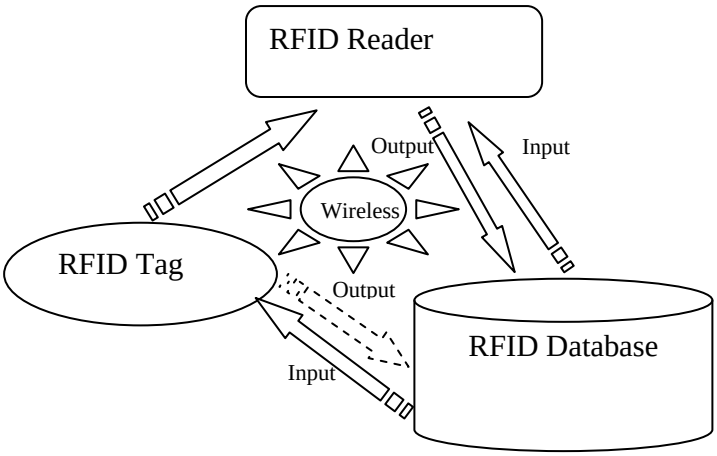


Figure 5-8. RFID data reading in site

BIM/RFID Framework Layout

An RFID system is an integrated collection of components that implements an RFID solution. An RFID system consists of the following components from an end-to-end perspective.

- Tag: This is a mandatory component of any RFID system.
- Reader: This is also a mandatory component.
- Reader antenna: This is another mandatory component. Some current readers available today have built-in antennas.
- Controller: This is a mandatory component. However, most of the new-generation readers have this component built into them.
- Sensor, actuator, and annunciate: these optional components are needed for external input and output of the system.
- Host and software system: Theoretically, an RFID system can function independently without this component. Practically, an RFID system is close to worthlessness without this component.
- Communication infrastructure: This mandatory component is a collection of both wired and wireless network and serial connection infrastructure needed to connect the previously listed components together to effectively communicate with each other. (Hu 2008)

A schematic diagram of an RFID system application strategy is shown in Figure 5-9. The concept of the RFID application strategy is as follows: (1) Place a transponder (a microchip with an antenna) on an item. (2) Use a reader (a device with one or more antennas) to read data off of

the microchip using radio waves. (3) The reader passes the information to different computer systems, so that the data can be used to create business value.

In steel structure construction, the current main purpose for using RFID is to track a steel member's progress and location. In this research, RFID can be regarded as the project information carrier. A passive RFID tag and low radio wave frequency RFID technology is enough for the current use.

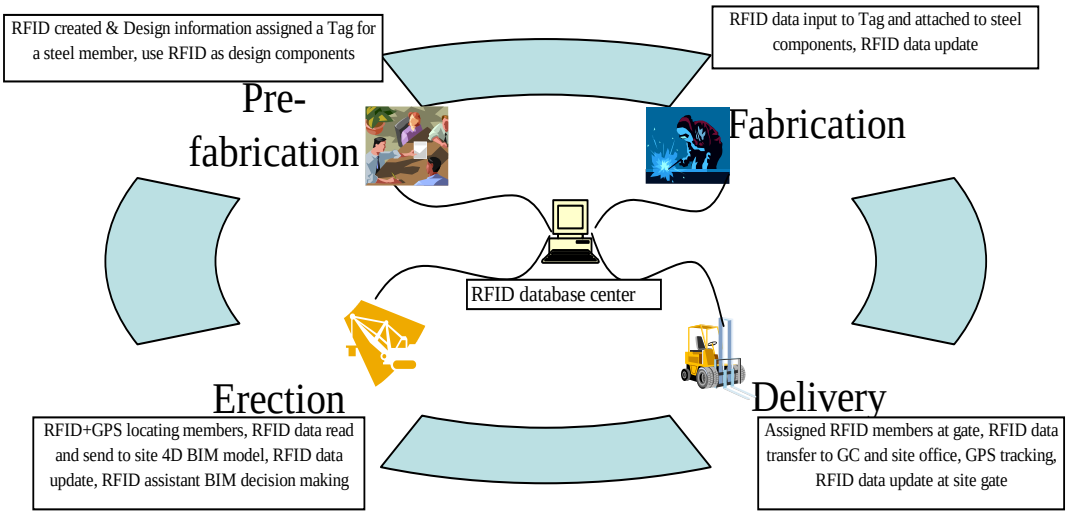


Figure 5-9. RFID application paths

The LF (Low Frequency) RFID, such as 125 KHZ tags, and compact-flash (CF) slot type readers can be chosen as the basic readers to be utilized together with personal digital assistants (PDA). The PDA also has networking functionality so that the PDA readers used will then be connected to a personal computer (PC). The stationary readers will be installed at the gate of a construction site. (see Figure 4-5) The RFID tags have to be attached to frame members by using magnet or glue after fabrication and painting with a rubber shell around the surface. Another use of tag may use clip cards for invoices to track the delivery and receipts of structure steel members. (Chin 2008)

The RFID data implementation can be divided into four steps: (1) design and prefab, (2) fabrication, (3) delivery, and (4) site erection. Figure 5-10 shows the details of the steps. The explanation of the steps is as follows.

Step 1. Design and Prefab

The design information for RFID tags begin from the drawing process. The steel IDs are generated from the architectural and engineering drawings. The architect or engineer may create a qualified RFID system in the specification for the project. The drawing data are sent to the contractor, who then sends them to the fabricator. After the fabricator has received the project information, the fabricator may select one type of RFID to submit to the contractor. The RFID tags, antenna, and reader's requirements information should conform to the specification manual for the construction project.

After the architect approves the RFID submittal (sent from the contractor), the sample will be sent back to the contractor. After the receipt of the approval, the fabricator will submit orders to RFID suppliers. At the same time, steel will be prepared for the fabricator's shop works. In this step, the data are transferred from the architect and engineer to the fabricator but may or may not come with the RFID information. A fabricator may work as an erector or a separate erector is hired as a subcontractor in the installation process. The data type in this step is 3D project model. The software options include: AutoCAD, ArchiCAD, Revit Structure, or Tekla.

Step 2. Fabrication

In this step, the fabricator needs to perform the prefabrication work in a shop in accordance with the shop drawings. The same RFID may be used in the base plate, which is shipped to the jobsite before foundation concrete has been poured. The RFID tags can be attached on the steel components when the members are ready to be delivered.

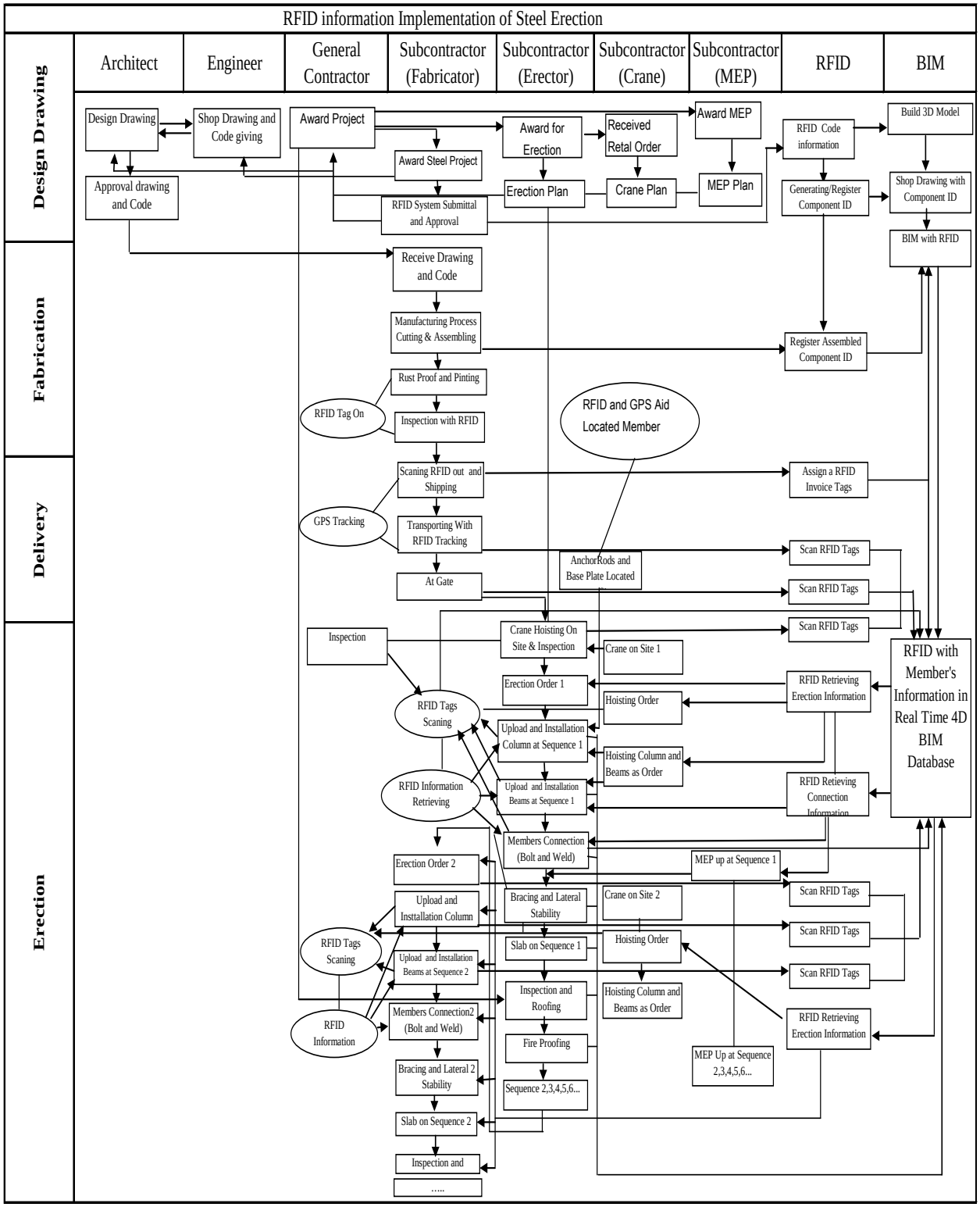


Figure 5-10. RFID data implementation flowchart

Before a RFID tag is attached to a steel component, RFID tags have members ID and other information in its memory. Finished steel members are placed in the fabricator's storage place or warehouse with RFID tags on them. After the RFID tag is attached to the steel component, the tag and the member will be inseparable. In this step, the steel component information is entered into the RFID, scanned in the storage, and tracked by a system. The tracking process covers the whole project construction duration. The tracking on RFID data might be longer than project duration if users need to track the building facility utilizations and energy savings. A fabricator begins to track RFID after fabrication. The information stored in the RFID tag may be just a serial number or code.

How much information can be stored in the RFID chip depends on its memory size. In this study, it is assumed that low memory tags are used because they are more economical. As a result, most of the information will be stored in the computer system of the BIM/RFID Framework, and the information is retrieved and shared via PDA. The data type in this step is CIS/2 and RFID. The software used in this step may include: AutoCAD, Vico, NavisWorks, Revit, Tekla, or CIS.

Some fabricators use an Automatic Manufacture System (AMS) to help their shops in fast-tracking, which means that they can fabricate steel while the steel design is still in process. Computer numerical control (CNC) is one of the AMS which can cut steel parts just after the detailing of the 3D model had been created. The fabricator usually has a large amount of drawings to deal with. Shop drawings normally cost a lot of money to detail, copy and store. The time spent on blueprints transactions among owner, architects and engineers is huge and is a potential factor for project delay. BIM design, AMS, and CNC make these transactions more efficient and consume less time.

Step 3. Delivery

When the delivery time has arrived, the steel components are sent out from storage. The electronic readers at the warehouse gate will scan the RFID tag automatically and update the information in the storage database of the computer system. The truck driver will have the steel information uploaded to his PDA. The invoice tags with RFID information can also be stored in the truck driver's PDA. A GPS system can track the truck and evaluate the arrival time. The data type in this step is GPS and RFID. The software may involve: AutoCAD, ArchiCAD, Tekla, Vela System, or Revit.

Step 4. Erection

The steel components will be scanned when the delivery trucks enter the jobsite gate. Then system will know which steel components have arrived, where they are unloaded and stored, and when they are going to be installed in the erection sequence. Upon delivery to the job site, the fabricated steel will be unloaded and placed on wood (or steel) blocking. The blocking allows chokers to be attached to each member for subsequent hoisting and erection.

The site installation manager checks the erection plan and gives orders to the crane operator and foreman. At this time, the BIM 3D model has been built up in the computer and will be waiting for component processing. The field foreman scans the RFID tags into the system. For example, the crane used for a project may be a 100-ton crawler-mounted crane with a 160-foot boom and a 40 foot jib. The boom is the main projecting structure of the crane and the jib is the smaller structure attached to the boom. There are many configurations and sizes of cranes available. Cranes are selected on the basis of cost, availability, speed, reach, and capacity (AISC 2008).

A special column hoisting device is used in the project. It has a release attached to a rope to facilitate its detachment from a column. After the column is secured with the required bolts, an ironworker starts the release directly from the ground to disengage the hoisting cable.

When the first column is hoisted into position, using ladders, ironworkers temporarily bolt the column. Prior to erection, the installer must consider column stability in accordance with safety standards and the AISC Code of Standard Practice. The installer may read the RFID tag and check the connection information before bolt connection. The information retrieved for the Erector is the component's RFID number and location, connection methods, bolt size and type, and welding type. Installers can read from their PDA about the information.

Every time when scanning the finished component, the RFID data will be transferred to the real time 4D BIM/RFID Framework in the office computer through wireless technology. The steel component in the model will change to a finished color, for example: from red to green (assuming red is the color of the not-installed-component).

After the erection plan finishes, the model color will be darker than the previous green, for example: from green to brown. Another way to implement this progress is to remove the RFID tag right before the member has been lifted to its location. All the removed tags are submitted to site office and scanned by PDA reader to change the statuses of the corresponding members to show "erected". With the RFID and PDA, all participants from the designers, the engineers, the fabricators, and to the installation managers of this project can read the progress of jobsite. Data type in this step is RFID and GPS. The software involved may include Tekla, Vela system, AutoCAD, ArchiCAD, Vico and Navisworks.

The main uses for RFID data in real time 4D BIM/RFID Framework is in project planning and scheduling, cost analysis, reporting, inventory management, and erection sequence

management. RFID data is also used for data sharing and transfer purposes in drawing, inventory, and supply chain functions. Among these functions, 4D schedule and planning is the core of the real time 4D BIM model.

RFID tags help in tracking the structural member's progress through erection. The RFID data is used to record the status of each member from manufacturing to erection at the construction site. The RFID data for each member are collected by using RFID readers and then the erection status is tracked in the real time 4D BIM model. This method gives an almost instantaneous status report of the progress of the erection plan to site and project managers or controllers.

RFID data can help with inventory management. For example, it could help in arranging just-in-time jobsite delivery. The RFID tracking system gives a record of the corresponding component information whenever it has passed the jobsite gate or each time it is scanned by readers. In this case, the supplier can check inventory and issue purchase orders on time. RFID erection data can help cost control when the optimal operation solution is sought. It could help convert a site delivery system into a just-on-time zero-storage plan. The steel component can be installed right after it arrives at the jobsite. This will decrease cost by saving crane operation time, cutting schedule time, and saving storage space. Another benefit of RFID data is that they can help with the cost control process in the crane and erection sequence plan. The crane operator can use RFID data to adjust project progress.

RFID data can help make real-time changes on drawings. RFID data can be used to manage the administration of new drawings and create a record for any changes. Shop drawings can be adjusted for member connection problems and supply problems. RFID data can show the change and record the new data. RFID data helps sequencing project management and

controlling the progress of work by providing advanced notices. For example, consider a project, where structural steel works were repeated in 5-day cycles for each floor. During detailing, the steel frame was divided into 6 sequences as illustrated on the erection drawing (see Figure 6-14). Sequences represent the order in which a zone or section of the frame will be erected. RFID data used to track actual erection could be used to improve the efficiency of the erection process in the sequence plan.

Proper planning of erection of the sequences allows parallel construction operations to take place. For example, while the erection crew erected sequence 2, the decking crew placed metal deck at the previously placed sequence 1. In this way, the deck placed at sequence 1 formed a work platform and reduced the fall distance when the steel contractor erected sequence 3 which was above sequence 1 (AISC 2005). At the same time, RFID data is used to show the details of the members in the sequence of work process. This helps the supervisor in adjusting the work tasks for the efficiency and optimization of different sequences.

RFID data can also be used to help the steel erection foremen and connectors by providing all information to them. The RFID tag contains data which can be read by erection foremen or connectors' PDA and correlative information can be retrieved from RFID system database or from preinstalled database using PDA. The worker can download the needed information right away.

The 4D BIM/RFID Framework and the simulation of the erection schedule are performed based on the sequence order presented in each 4D model. In addition, the color of each 4D CAD model steel member changes depending on the progress information collected through RFID technology.

The overall progress status as well as the member progress is also identified. The application of RFID in the structural steel work enables more accurate logistics and progress management. The application leads to the reduction of risks, including material loss and schedule overrun, by identifying production and delivery information in advance and by monitoring the erection process on a steel member unit basis (Chin 2008). The implementation of RFID technology in construction has great potential to help contractors and subcontractors in the fabrication and erection of steel structures. The RFID data can help the real time 4D BIM/RFID Framework to be more efficient in modeling the process and to save time and money.

An Example of RFID Works in Steel Member

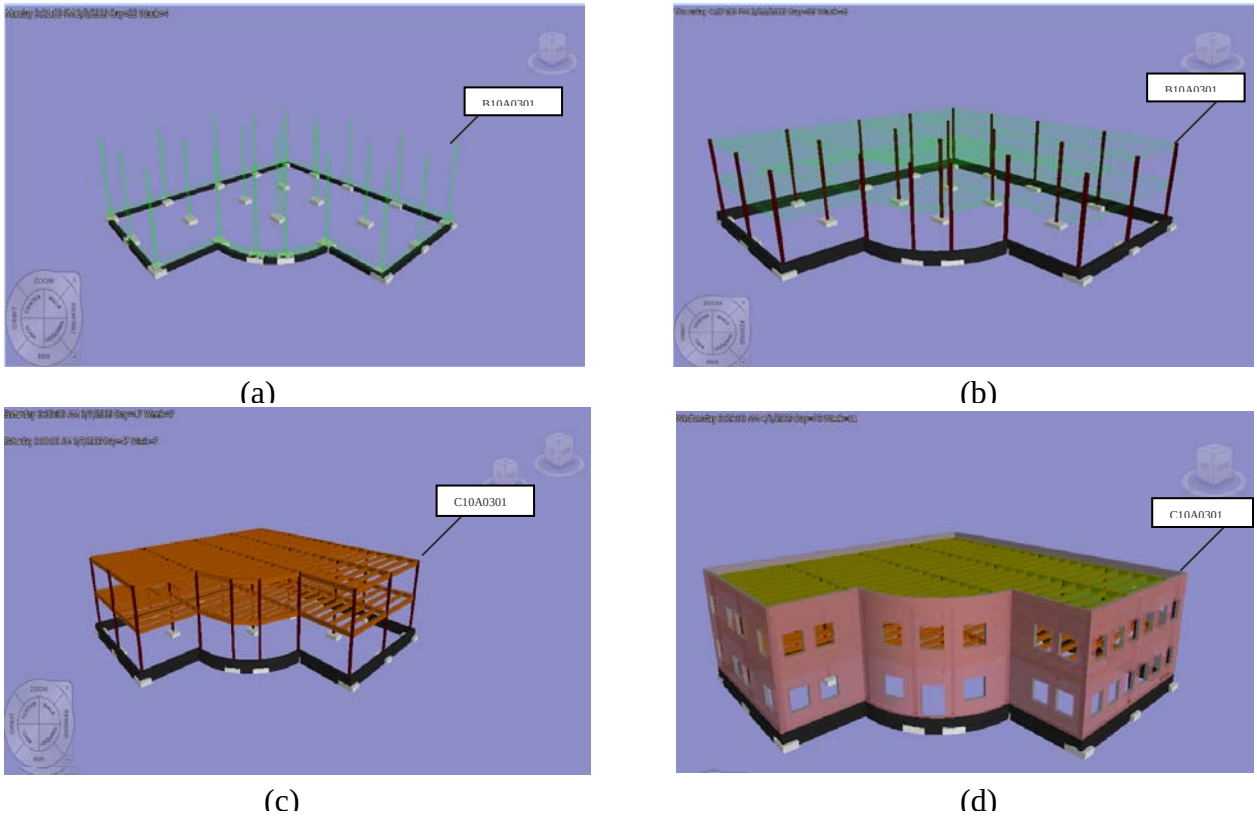
RFID technology currently is slowly being accepted by steel fabricators and erectors. A single use for tracking the member location is not worth the use of an expensive RFID system. The barcode system has been used by many steel companies since end of last century. What the RFID can show to AEC and site personnel? Is it worth to have RFID to use in jobsite? Here is a case study example to resolve these questions.

In the Figure 5-11 (a)-(d) show how a column changes in a simulation of a multiple floor structural steel 4D model.

Figure 5-11 (a) shows the column simulation in Sequence 1. The column RFID # C10A0301 in this 3Dimage has not been erected. The information the RFID Tag of Column #C10A0301 includes: Steel features Mill, Manufacture, Inspector, Storage, Delivery and Site location IDs and Dates. If the memory is big enough, other information such as connection methods, welding methods, and so on may also be included.

Figure 5-11 (b) shows columns that have been built up. The same column has been erected but not connected. At this point more information will be added to the RFID database – installation date, crane operator, superintendent, erector, etc. The RFID tag currently is not

available for reentering information because of the costs involved. Information is input to the RFID database system through wireless PDA reader or manual typing. This task was also performed at Sequence 1.



(a) (b)

(c) (d)

Figure 5-11. 4D BIM Model shows a column with RFID changes (Revit 2008)

Figure 5-11 (c) shows the work at Sequence 2 and 3. The column #C10A0301 was connected with beams #B20A0301 and #B20B0301. The updated information added on to this sequence is the connected beam information, connected inspection information, erector and connector, crane and operator, safety issue, date and location GPS points, maintenance requirement, bolting and welding methods, bolt size and specification, etc. The RFID Database system is updated with each steel structure components situation. It should be inspected in detail by the foreman using RFID reader to check the components RFID tags and connecting pieces.

Figure 5-11 (d) shows the building finished with the outside wall in place. The Column # C10A0301 now has all its connection information updated including its attachment to the walls and roof trusses, Girders, Bracing, Plate and Rod. Every connected members and its information may be found by checking its RFID tag and log into the RFID database system in the BIM/RFID Framework. The construction projects have been completed and the RFID information of Structure steel components is updated on time. This RFID information will be kept in the building facility model to maintain the building life cycle situation. In this way, the building components can be monitored piece by piece by using RFID records and maintaining the system.

There are some items that RFID tags cannot be attached to. For example, small plate pieces, bolts and welding material, etc. How does RFID technology work for them? Although these small pieces cannot have tags attached to them, they still need RFID numbers to identify them. Their features and connecting information would be read from the RFID database system. Small piece members can name RFID by group or with attached beam or column. Even piece too small to attach a RFID tag, it is still necessary to assign a RFID code so that RFID can represent every member.

The RFI (Request for Information) and RFC (Request for Change Order) can be stored in RFID database too. There are two ways to handle RFI or RFC questions. One way is to solve the RFI and RFC all manually; the other way is to use computer system to help solve the problems. Historical RFI and RFC documents are saved in RFID database so that BIM decision model can find options for RFI or RFC from similar cases. Using the RFID database and the BIM/RFID Framework to find an answer and to request the manager’s approval usually is better than the manual method.

In the case, the connector from RFID checking result of design beam #B10A3102 has a loading warning when use A43 with double bolts connecting with column #C10A3101. After the user checks the RFID database and has found the reason because the wrong sides installation for #C10A3101. A shear plate welded on #C10A3101 should face outside but is installed facing inside. Outside bolted connection is not strong enough to hold a canopy attachment. The user writes a RFI from their PDA system and scans connected beam RFID tag and enters the plate RFID. The system uses its wireless connection to send the RFI to the site BIM/RFID Framework. The BIM/RFID Framework works for sending the RFI and data searching immediately.

There are three methods to treat this problem from the RFID database.

(a) To reinstall the column.
(b) To welding another shear plate on another side in the same place.
(c) Redesign the bold connection and changing to stronger bolts.

At the same time, the BIM/RFID Framework has cost analysis and building code search capabilities. The Project Manager receives the three options and a cost analysis (by checking RFID database found the cost data for plate and bolts) of the options for the RFI and RFC request. After a few minutes, the Project Manager decides to take the Change Order for the option 2. After an RFID search from the project BIM/RFID Framework, there is one of the required plates on site which is to be used for the next day's job. Then, a parts order send to supplier and a RFID system showed up the plate location. This total change order used 20 minutes from the site problem to sending out a purchase order (P.O.).

Figure 5-12 shows the different RFI flow between tradition method and RFID database method. In the traditional method, the RFI needs to be sending to Superintendent, PM, and AEC, then they go to find the answer and they issue a P.O. Usually RFI take at least two days for the process. The BIM/RFID decision making model significantly shortens the process, in the system,

the AEC, Superintendent (SI) and PM knows about the RFI and followed options at about the same time.

By using RFID and 4D CAD technologies, a real project in Korea saved 17 percent of project progressing time and 72 percent of stockyards (Chin 2008). It shows RFID can be used in a BIM model with 4D tools.

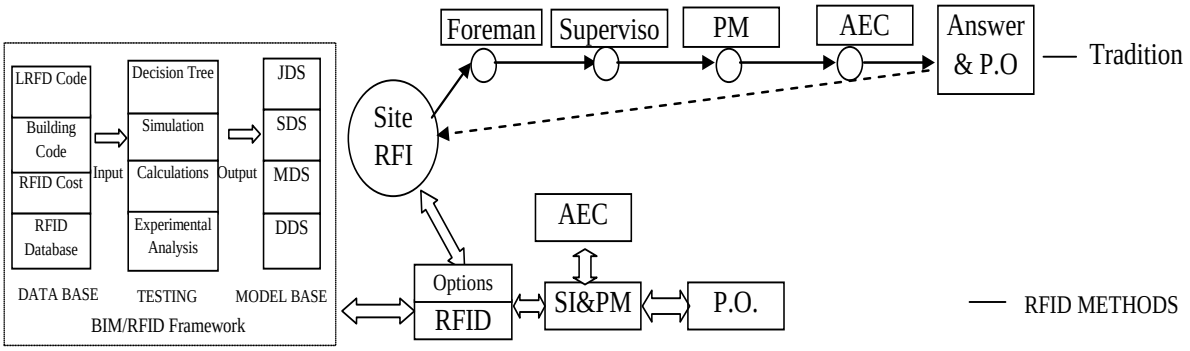


Figure 5-12. Tradition RFI or RFC versus RFID jobsite flowchart

If put every items with RFID to mark the change, the BIM/RFID Framework would easily create an emergency reflection system to deal with jobsite uncertainty incidents. For example, a lost of Beam B01A0310 as a steel structure item may bring changes I in the plans for crane CR01A5, Cost -E01A increase and OSHA Regulation 29 CR1976 warnings.

CHAPTER 6
CASE STUDY

In this chapter, an example will be used to show the concept and logic of the BIM/RFID Framework. A multi-story project example will be used in this chapter. Because the research is focused on steel structure construction, the multi-story project is built up digitally by using Autodesk Revit for 3D modeling, the Suretrak for scheduling. In specific, this chapter also uses a steel component example to show the steel component's status, specifications, and locations on the drawings and on the job site.

Case Study—OCW Building

The OCW building is a four-story building located in Little Rock, Arkansas. The OCW building is used as a classroom/office building for the College of Engineering. The building consists of a steel structure. It uses brick as exterior material. It has an auditorium and a bridge to connect the existing neighboring buildings to it. The bridge connects two buildings at their second floors. The estimated budget of the OCW building is approximate $10 Million. The project is expected to be finished in 17 months.

The construction management process of a project involves making choices to find out the optimized solutions for problems or situations emerging during the project. Each member of the project team will make their own choices to satisfy both the requirements of the project and the best benefits of its own company.

In the decision-making process, an individual should collect all the project-related information as that they can. The decision-making process in construction project is a complex task. In order to simplify the process and provide assistance in the decision-making process, the proposed system uses Building Information Modeling (BIM) and decision making technologies in the construction management process. Morphological analysis or General Morphological

Analysis is used in the proposed system. Morphological analysis or General Morphological Analysis can be used to explore all the possible solutions to a multi-dimensional, non-quantified complex problem.

As a problem-structuring and problem-solving technique, morphological analysis was designed for multi-dimensional, non-quantifiable problems where causal modeling and simulation to not function well or at all. By reducing the number of possible solutions through the elimination of the illogical solution combinations in a grid box, the proposed system will help users to reach the optimized solution. The following example shows how a construction company can use the proposed system to handle complicated construction situations or problems.

BL Company was called ‘Bad Luck’ by workers after being awarded the contract of the OCW building. From the beginning of the project, everything was getting worse and out of control. The project team has not yet made any firm decision on any of the problems in this project. Various impact factors and hard-to-predict results contribute to the hesitation and discrepancy in the decision-making of the high-level managers. The VP of Operation and the appointed project manager were just fired because they were responsible for the company’s benefits lost.

The Board’s chair of owner, Mr. Oregon, had called them three times about the project delays. In this case, the company wants to get immediate help from a consulting firm which has BIM tools that can be used for this big steel structure project.

ABC consulting signed a BIM contract with the GC which was approved by owner and architect. It uses BIM and DIS (Decision Information System) in this project based on its duration and other situations. Figure 6-1 shows the differences between a traditional steel structure project process and the project work flow using BIM methods. It also shows the

progress changes and duration changes. In traditional process, the design parts may finish earlier than the BIM. Using BIM methods can save time in the case of a request for information (RFI), transmittals delay, change orders, and jobsite mistakes.

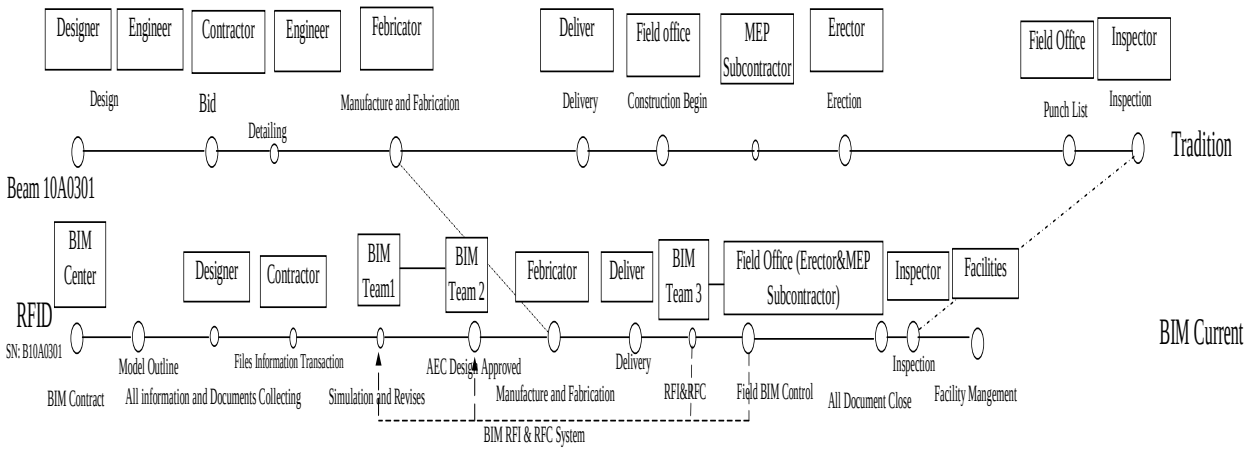


Figure 6-1. The BIM/RFID and traditional methods process for a steel structure project

RFID is included in this BIM project and it impacts the entire project. It makes it more convenient in managing projects, especially when tracking project process and erection connection details. In this project, the drawing design had been finished. For the ABC firm the first step is to transfer the 2D drawings to a BIM/RFID 3D model. The transfer process involves the following steps:

Step 1: Transfer a 2D CAD drawing to a 3D BIM/RFID.

The Architecture firm has a CD with 2D CAD files and drawing documents. After some considerations about this project, the ABC project manager has decided to use 2D-Revit-Navisworks applications with a 4D BIM deployment later. Figure 6-2 explains the architecture of the transfer process of project files. The drawing format from 2D to a 4D drawing, and members are assigned with RFID each. Other documents come with RFID members also. RFID use as activity label can display the project schedule as well.

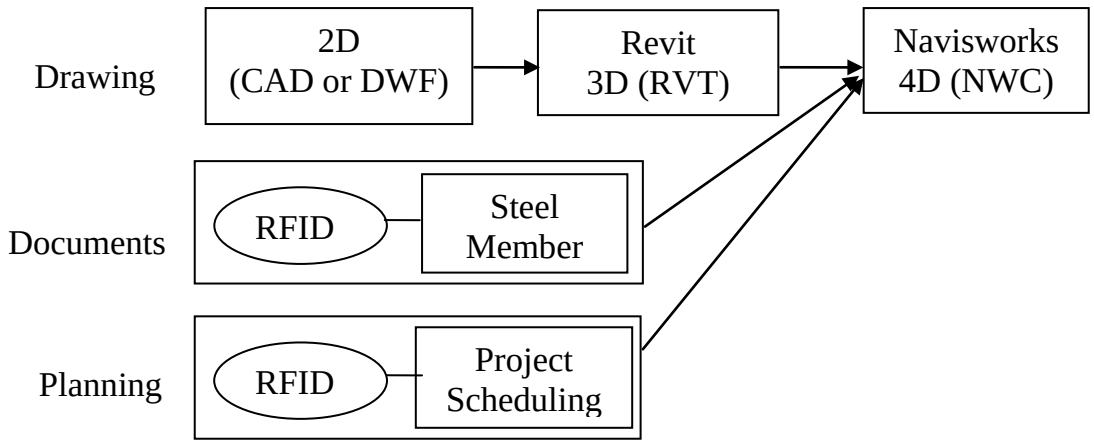


Figure 6-2. Project files transfer architecture

Step 2: Use RFID to identify each steel member in project and input RFID to BIM/RFID framework.

RFID is used to identify each steel member so that the follow-up digital file has a connection code for combination. Also the files using RFID can be easily tracked with location and progress. The RFID number can be normally used number or a specially created numerical code for a single project. The AISC has a building marking system for steel member identification which can also be used in RFID tracking.

Step 3: Make a new project schedule

The project schedule in this example uses Microsoft Project as the scheduling software. One file format of Microsoft Project is MPX. The project schedule shortens the way to transfer a BIM project into a Navisworks format file type because Navisworks can open MPX type file.

Step 4: Simulation and testing RFID and 4D BIM tools

Before using RFID as a member identification tool, the steel member's number is only a number which means it does not carry any practical use except a way to distinguish one item from others. After using RFID to identify steel members, the numbers enriched their meanings and carry lots of information about building process, connections, and more. Using RFID to

simulate the project progress makes the Architect, Engineer and contractor (AEC) able to track the details of structure steel erection. With the aid of simulation, users can forecast problems to avoid possible adverse situations.

Using RFID in 4D BIM can help users build an advanced scheduling track. The scheduling track can help them see the details in the schedule. They can use the scheduling track to monitor and control changes and buffers in advance. The scheduling track also makes it possible to revise the project buffers or request an RFI in advance.

Step 5: Use the BIM/RFID framework to control the project.

After the simulation of the project and tracking the project schedule, ABC firm rearranges the schedule buffer in order to catch up on the project delay. Then it became time to set up a site office to control the project.

In this case study, the BIM team needs to develop the optimal erection plan for the delayed project. This plan should decrease the duration of the project and meet the technology, cost and safety requirements as well. To use the BIM/RFID decision making model, four major questions need to be answered:

- First is determining the optimal erection sequence. The sequence needs to satisfy two parts: the steel components erection order and the suitable sequence arrangement.
- Seconds is to establish the crane plan. The crane plan needs to satisfy two parts: crane numbers and optimal operation control.
- Third is to establish the optimal delivery plan. This plan should have the optimal driving route and optimal timing.
- Fourth is to establish the safety plan. The reason to list the safety plan as a major question is because any OSHA violation would directly cause a serious project delay and cost increase.

Figure 6-3 shows the BIM/RFID Framework with the details for the erection plan. It shows the BIM model using RFID for an optimal erection plan. In the Erection Order process, the

sequence plan and steel member order for hoisting up is the main consideration. The sequence plan includes sequence arrangement and job arrangement. Sequence arrangement needs to think about how to arrange the sequence for a safe and effective work space so that scheduling is optimized and no barrier between sub-works can be achieved. For example, the RFID database has all the steel components' information. The weights, sizes and other features of steel members are considered as factors for developing the erection plan. The locations and connections information of steel members need to be considered to make an optimal plan.

When inputting the data in the BIM/RFID Framework, the model will run a test for possible erection sequence and order. After simulating the process, if the result fits cost, technology, and safety requirements, multiple options may be suggested.

The next step is to output these options to BIM/RFID decision support systems such as DDS and JDS. After comparing the results, the optimal answer will be selected and all project information such as cost estimating, scheduling, and other subcontractor work change will also be calculated. RFID data layers in this step work as a smart coding to corporate the model.

Job arrangement focuses on job planning and work force arrangement. All these tasks need to be simulated by using 4D BIM/RFID and system integration methods such as an optimal manufacturing system. RFID as a digital information carrier has a coding system and a number. RFID is the basic condition for automation control, which can go through the decision steps of BIM/RFID Framework. In this stage a JDS (Jobsite Decision System) may be used more than other systems.

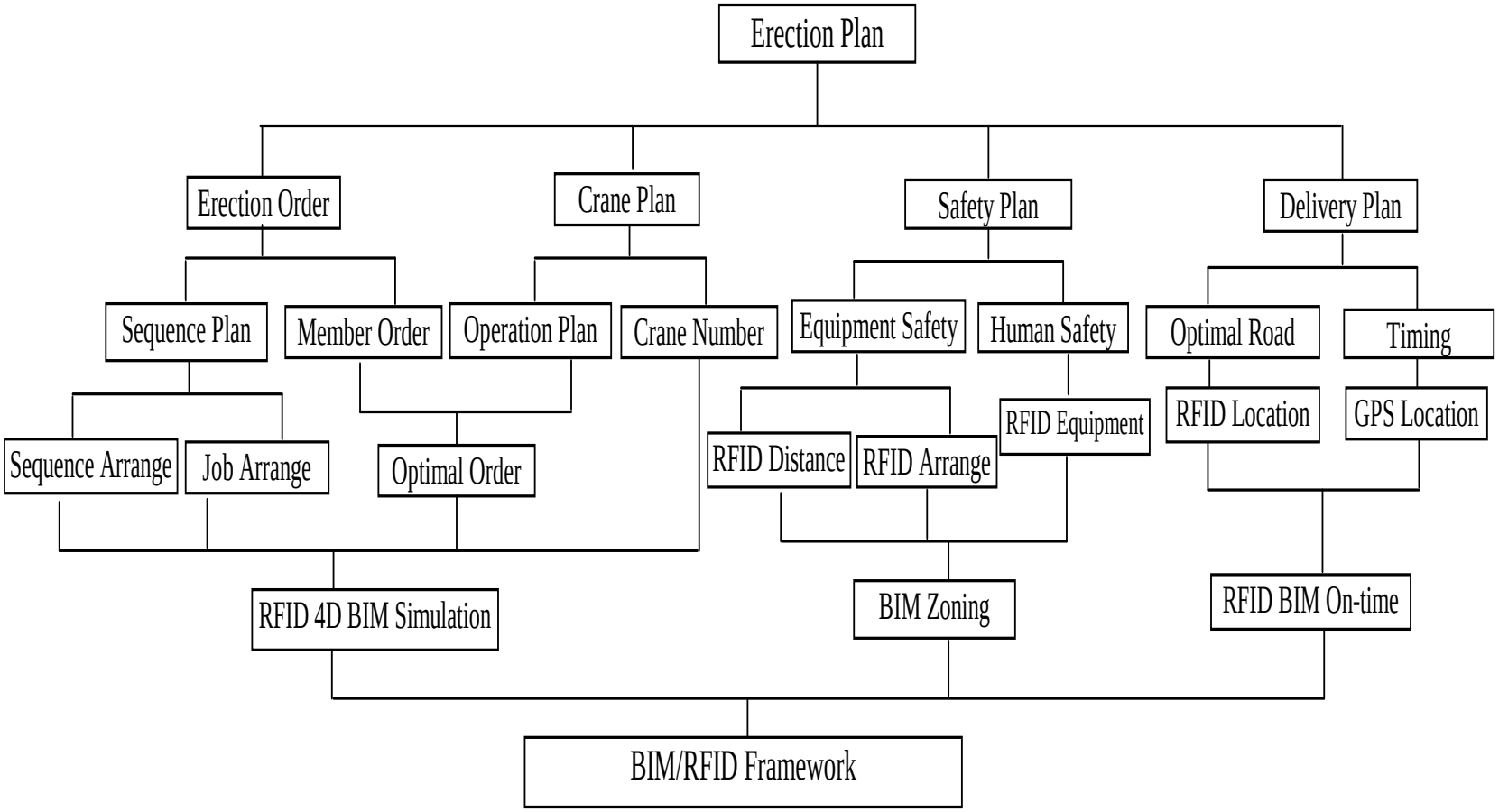


Figure 6-3. BIM/RFID Framework for optimal erection plan

How RFID Creating an Erection Order

Figure 6-4 is the process of RFID creating an optimal erection order. From the RFID database, each member's features and factors can be listing and grouped by sequence, floor location, bearing factor, size factor, etc. These items are ranked by different priority from high to low. Then a basic erection order is build up. In real project, the project sources are changes and uncertain sometimes, such as worker numbers, delivery condition, equipment condition, utility available, and other uncertainty changes.

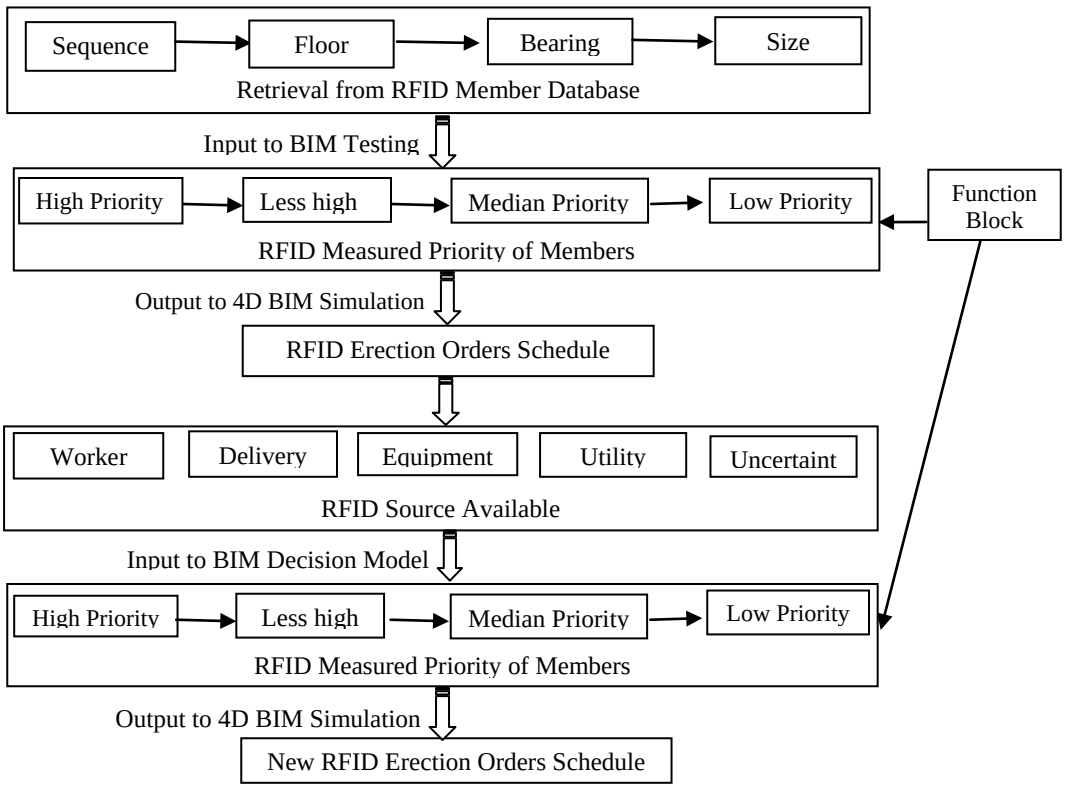


Figure 6-4. Detail of RFID database creating erection order plan

When sources varied, the erection order and project schedule should follow the changes. Using RFID coding system, the order schedule has to run for changed factors as of priorities to create a new erection order. For example, the first floor and loading column is the High priority, adjustable beams is median priority when the attached members is the low priority.

In this progress, RFID as a smart coding system to check and to match building code and erection factors from RFID database. The 4D BIM/RFID Framework simulation function run for the result of erection order to verify its rationality.

RFID and 4D Simulation for Crane Plan

Crane Plan includes two things: operation plan and crane numbers. Operation order is associated with member order of erection order. The number of cranes depends on the calculation of the work load, cost, and schedule. Similar to the Erection Order, RFID is necessary for system to simulate in a 4D BIM environment. How many cranes are needed for the project depends on a detailed calculation and simulation. This question can be resolved by using the BIM decision making model.

Because the crane erection order plans same as members erection plans. The process of crane erection order plan is same as Figure 6-4. The source used to design the number and crane location from RFID database.

Figure 6-5 is the RFID creating of crane plan processing. The crane features are listed as a priority sequence. They can use RFID retrieved from RFID database.

RFID and BIM Controlling Delivery On-time

Delivery Plan includes road selection and timing for jobsite needs. The major function for RFID is tracking and identification. RFID system with GPS system is used in delivery tracking and supply chain for years. Its advanced functions have been highly praised. RFID database with BIM decision making system can help to develop a better delivery plan as well. The details will be discussed in the following on-time delivery case study. Figure 6-6 is the RFID creating of delivery BIM on-time. The function block in it is a Delivery Algorithm block. RFID database and project sources are discrete data, the function block make them logically and orderly.

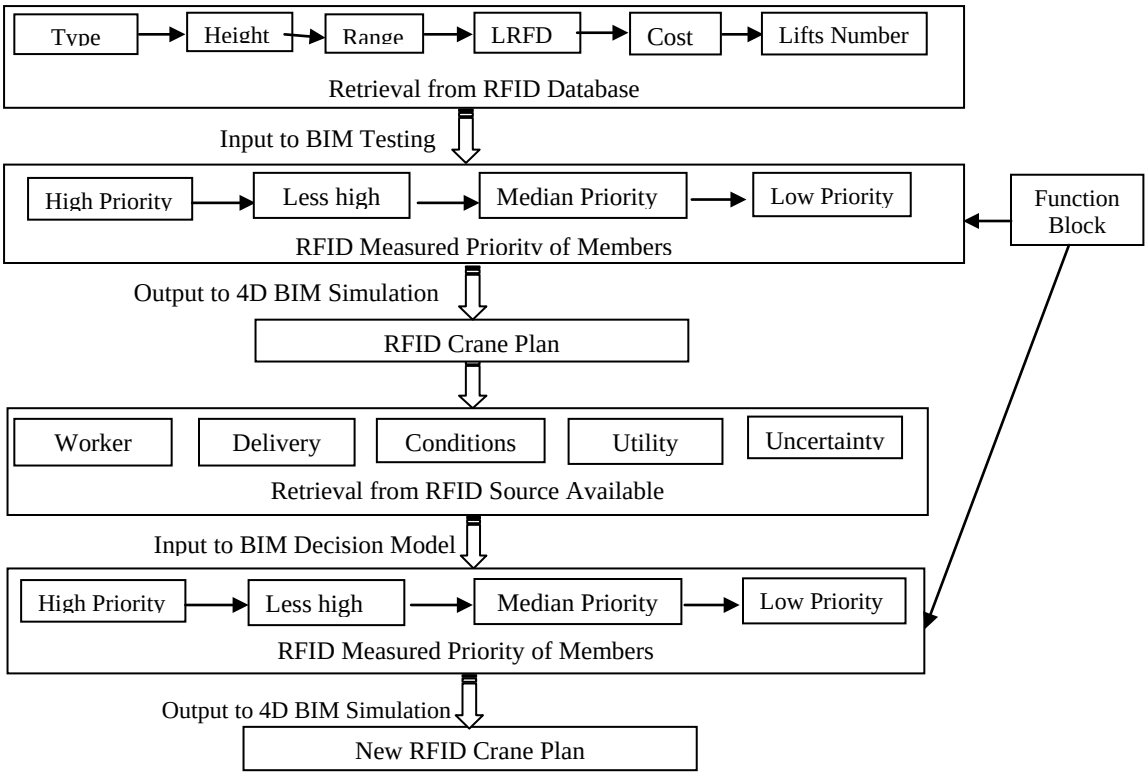


Figure 6-5. Detail of RFID creating a crane plan

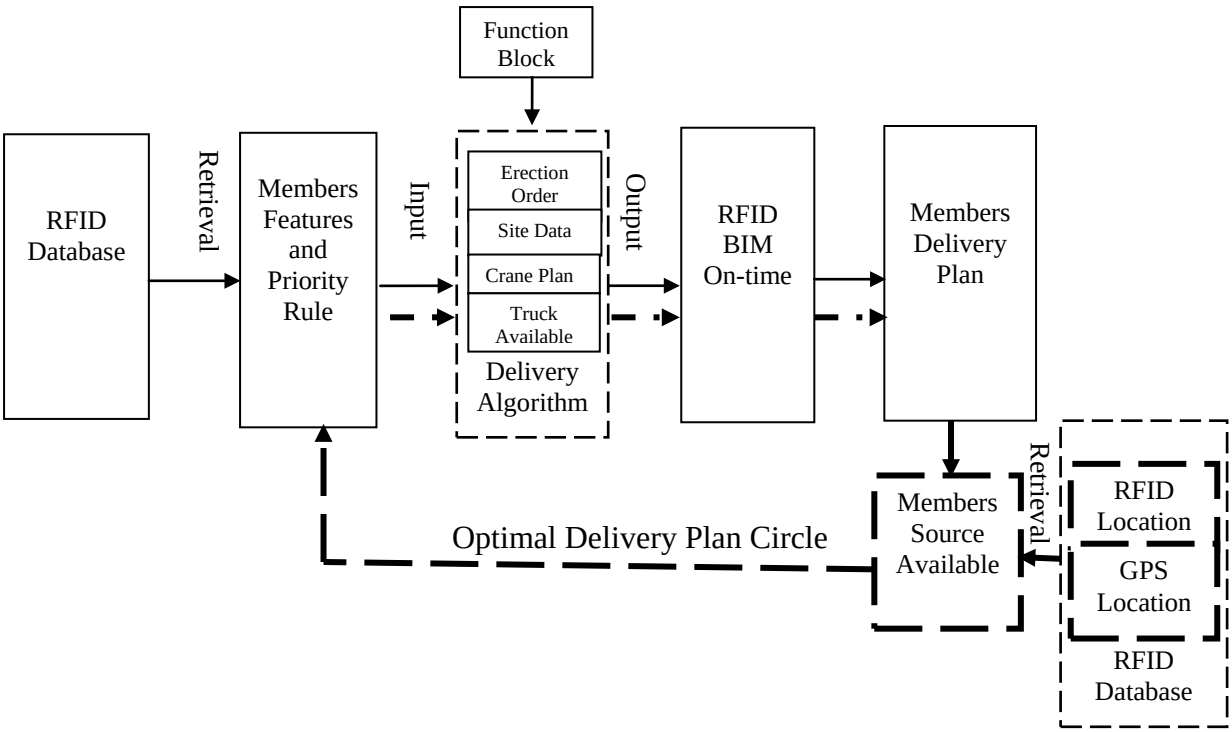


Figure 6-6. Detail of RFID creating a delivery BIM on-time plan

A construction project—whether it's an office building, factory, bridge, airport or other facility—is a highly coordinated, complex operation that must run according to schedule. Any delay in a construction schedule can be costly to the contractor in terms of salaries, leased equipment and maintaining security at a job site for longer than was budgeted.

Figure 6-7 shows RFID Data flow during delivery process. RFID tagged members loaded in the truck with GPS device. The RFID system sends members information to GPS system, then through GPS system and wireless transferring their real-time location to RFID database. The BIM 4D model can simulation an erection order depends on the estimating steel arriving time. GPS and RFID develop a wireless position tracking system, make on-time delivery possible.

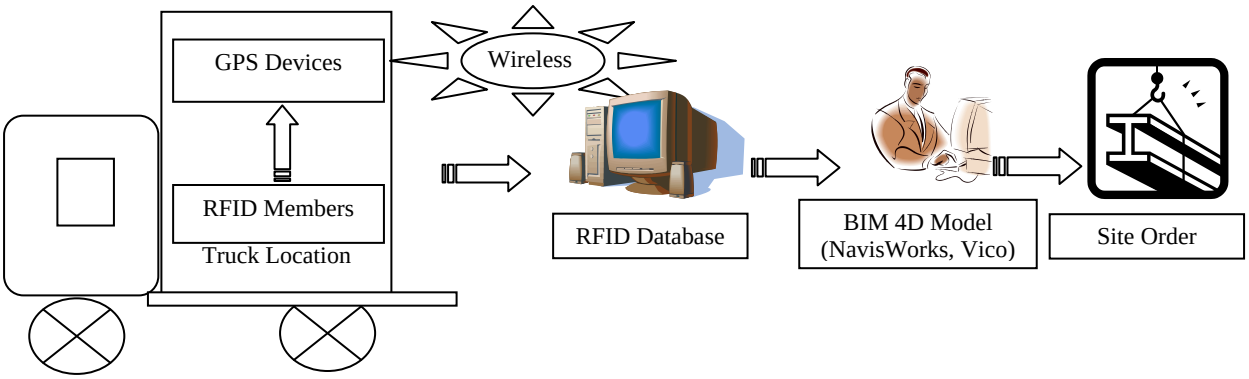


Figure 6-7. RFID data flow during delivery

RFID BIM Zoning

The Safety plan includes equipment and human safety components. RFID and GPS have been used to control work space and riskily distance warning. RFID safety warning equipment for workers has been designed to be worn on a hardhat and helmet too. It can protect workers from fall and other accidents.

Figure 6-8 is the detail RFID creating a BIM zoning for safety plan. In this data circle, RFID safety database for equipment safety and site work safety are separated selected.

The items for site work safety data are different than items using at equipment safety. For example, the type in site worker safety is as of job type when in equipment safety is equipment type. In site worker safety, the height is OSHA jobsite length and height requirement. In the equipment safety, the range is equipment working range and height features. As same as erection and delivery plan, the safety plan is adjusted with source available also. When project has source shortage or other uncertainty accidents, the new RFID data will run the BIM zoning model again to make an optimal safety plan to cover the change.

Safety algorithm is a computer numerical program which uses smart coding and artificial intelligent techniques to make an optimal plan for given resource. The RFID database should include OSHA regulations, building code, equipment operation menu, and so on. The zoning control also needs network and security cameras monitory systems. A functional network can serve a good RFID data transaction so that BIM tools working accurately and effectively.

Figure 6-9 shows RFID in BIM zoning safety control system. A designed RFID location system has readers sited on required positions. Special RFID tags were attached on equipment and workers' hardhat or helmets. In an intranet environment, RFID location system can arrange a distance for safety control and locating riskily locations, such as hoisting area, flammability area, falling zone, and heavy equipment path, then making a warning system for danger movement or possible safety violation. For the worker with RFID hardhat on if he entered any of these danger locations may receive an alert or a reflecting alarm. Also it may have different frequencies to zoning the safety.

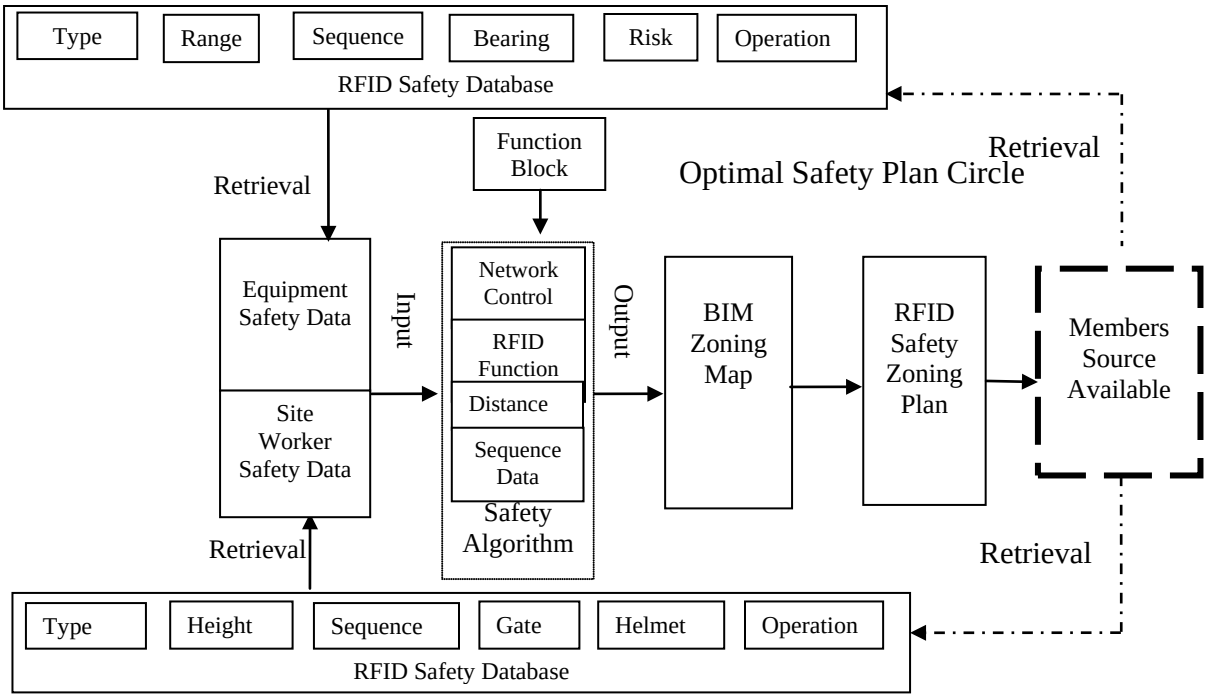


Figure 6-8. Detail of RFID creating BIM zoning for safety plan

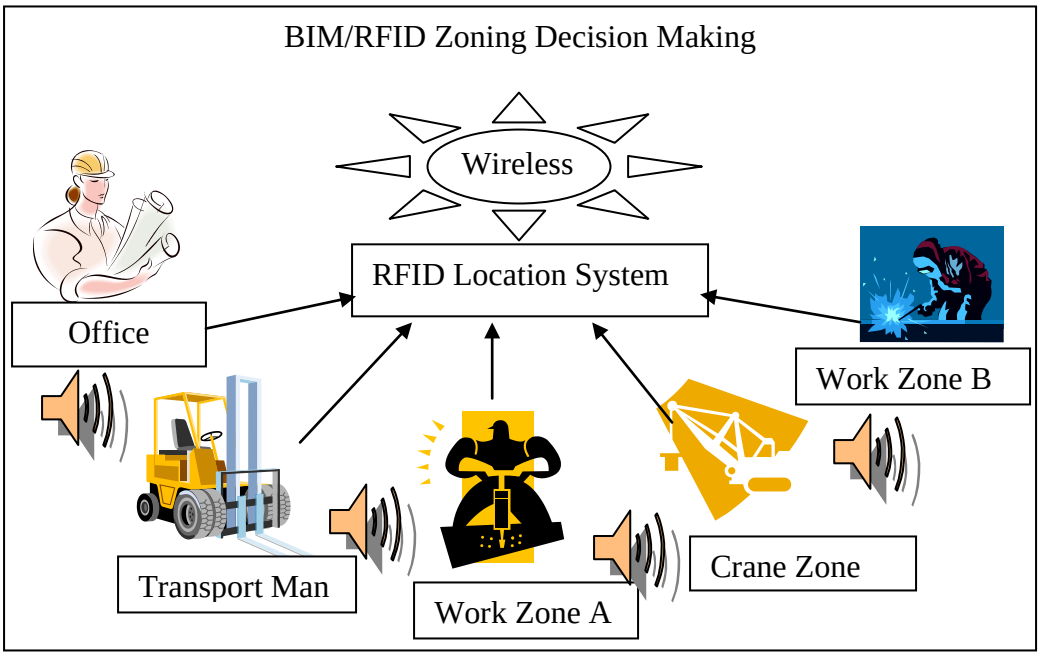


Figure 6-9. Sketch map of BIM zoning safety control

Case Study—S Steel Company

Background

The following is the background description of this case study:

S Steel Company is one of the largest steel contractors in the US. It has 2000 Employees in its Little Rock, Arkansas division. Its three main fabrication shops are located on a total of about 60 Acres land. Figure 6-10 shows S Steel Company's organizational chart.

Among steel contractors, S Steel Company has the most advanced technology programs and training resources. They have been listed as "top 5 steel contractor of the year" for more than 10 years.

Task and Plan

The president of S Steel Company went to the AISC conference and learned some knowledge about BIM. He has a very strong feeling that BIM can do excellent work for their projects and can help in cost savings. After coming back to his office, he holds a meeting with managers and made a report on BIM research and a feasibility study.

The first thing that needs to be done is to find out the easiest way to rearrange their current resources to deal with the new BIM task.

Then they have to check whether current BIM technology is adequate to support their jobs. This task is assigned to their technical support department which is associated with Dr. Z from the Building Construction Department at University of Arkansas..

Here are the questions they have to find answers to:

- What are the right BIM tools for their work?
- What kind of organizational frame change is needed to fit this BIM model?
- What is the workflow that BIM will bring to them?
- What is the budget for this work?
- What improvement does the BIM technique contribute to their jobs?
- What are the benefits of this change?

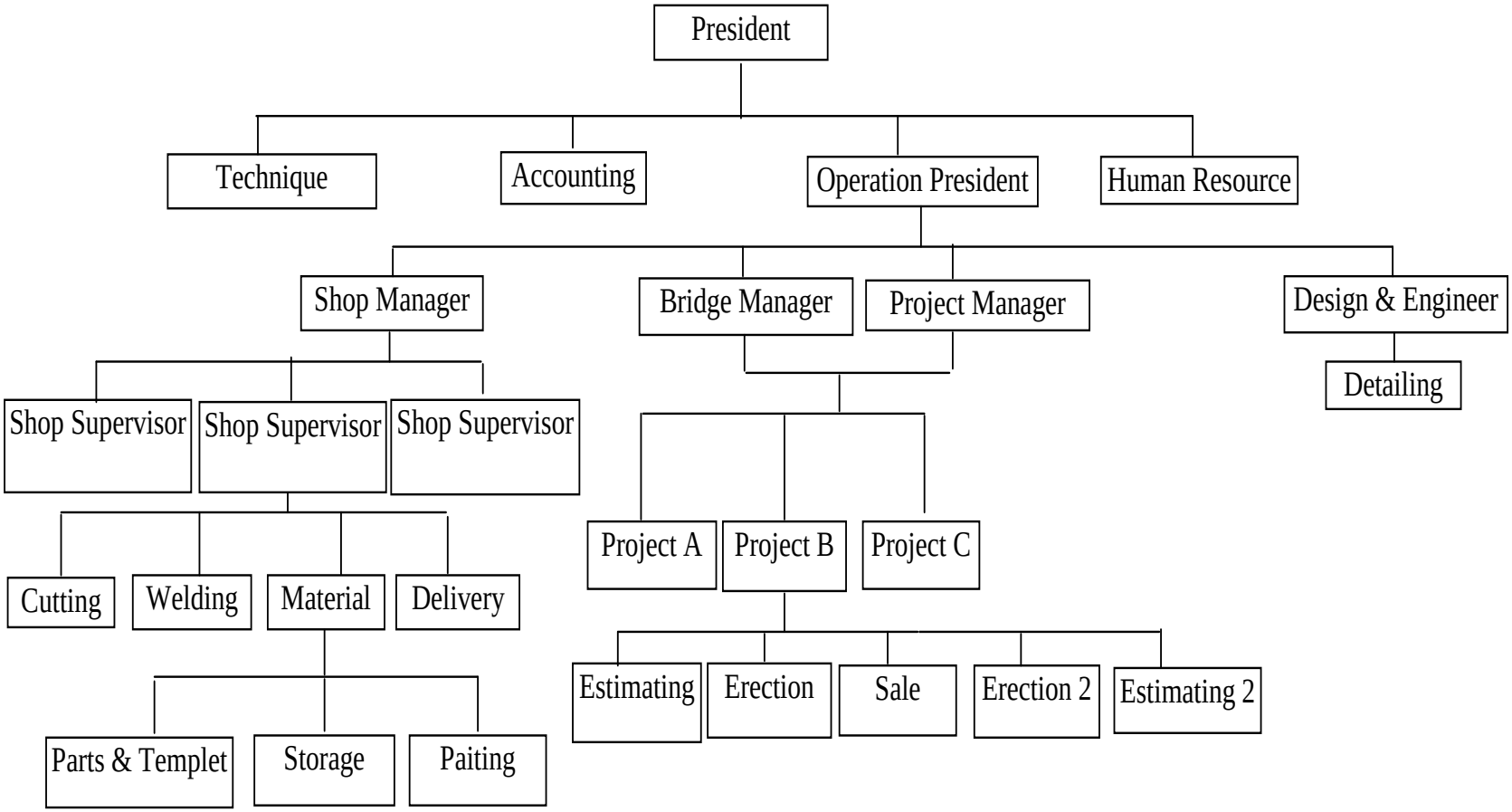


Figure 6-10. S Steel Company organization structure chart

After the review of the company's existing software and equipment, they know they have AutoCAD as main design software and SDS/2 as detailing software; MS Project 2007 as project scheduling software: MS Excel as estimating take-off software, and other software used at their shops. A fully ranged (Computer Numerical Control) automated fabrication equipment is used to operate steel plate-cutting and hole-drilling. Shipping methods include common carrier, Union Pacific Railroad, air cargo, and river barge shipment.

Re-organization for a BIM Model Base Company Structure

The first challenge is to reform the firm's organizational structure. The firm has over 30 years of history. The risk of change to the firm's organization structure is obvious. A tough conflict would damage the whole program. So, after meeting with department managers and company board members, the result of discussion is a compromise that the company organization would be changed as little as needed so that it can support a BIM model. Also, the change plan should maximize the use of current equipment and software. After research on effectiveness and compatibility, they decided to use an organization structure chart with BIM function combination as shown in Figure 6-11.

In this design of the organization, one BIM manager leading functional BIM department is under the Operations President and the same level with construction PM and bridge PM. His duty includes:

- Responsibility for all BIM related work, including but not limited to, BIM models, shop work continuity with BIM control tools, and on time BIM support.
- Associate with general contractor project manager and their architects and engineers to deal with each project RFI and RFC problems.
- Responsible for BIM team works arrangement and assignments.
- Verification of BIM design, engineering work, and estimating results.
- Control technical support and BIM networking safety.

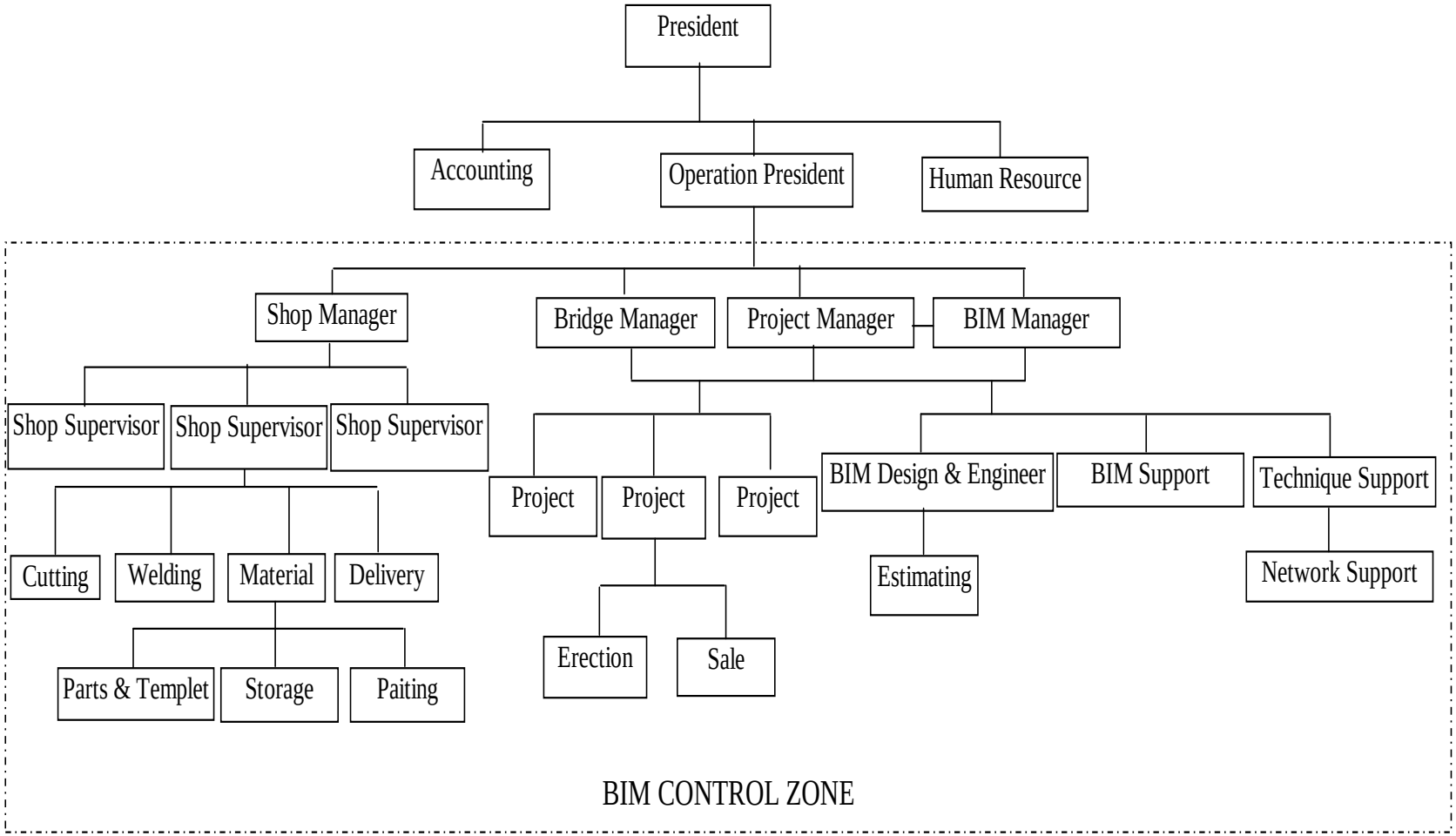


Figure 6-11. S Steel Company simulation of using BIM organization structure chart

- Control all BIM tools purchases and maintenance.

The following are changes caused by BIM organization structure:

- The former design and engineer team has to finish training on using all BIM tools and be skillful with all detailed software functions. They report to the BIM manager for BIM design and engineering work.
- The technical support personnel have to learn BIM tools as well. They have to keep the BIM network running through projects. They also need to maintain all hardware and software, and keep all company and project documents safe.
- The estimating department is merged with BIM design and engineering as a sub-unit. That is because some BIM tools have strong estimating functions.
- Shop work positions are kept. All the shop sequences are controlled under the BIM model.
- The BIM control zone covers all stages of work and positions under the operation president. All departments are connected with the intranet network system and are controlled by the BIM model.

These are the minor changes to the organization structure plan so that the company can keep its traditional work style. The BIM model is only a new tool for construction work. Any costly changes may cause more conflict in the work.

The BIM Model Cost and Implementation

This BIM model would have decision-making functions in it. All resolvable decision making questions are listed under a search menu. Users can navigate these questions in a catalog box. Users can fill information in different dialog boxes when requested. Users can use key words to search for match-up questions and then select the proper decision making model.

S Steel Company work packages include fabrication and erection subcontractor work. Architects should give them drawing documents. If they already have the architectural drawings, they have to translate these 2D or 3D drawings to SDS/2 format before using Navisworks.

The fabricator is a type of ETO (Engineer-to-Order) component producer. The S steel shop is using a CNC Automation Fabrication System and an Intranet in the design and engineering

department so that the drawing orders can be sent directly to the machine and be created at the moment. CNC Automation Fabrication System uses the same 3D SDS/2 shop drawings that the BIM/RFID decision model uses. The BIM/RFID Decision Model can coordinate with this situation. It uses Navisworks with the original SDS/2 3D shop drawings as well.

BIM Brings Benefits to S Steel Company

BIM can reduce mistakes that may happen through all stages of construction. SDS/2 is considered as one of the BIM tools. It can develop a 3D detailed model and generate connection detailing documents for either fabrication or erection. It can improve the efficiency of most existing steps in the 2D CAD process by increasing productivity and eliminating manually maintained consistency across multiple drawing files. BIM changes the production process itself by enabling degrees of prefabrication that have remained prohibitive in coordination costs with existing information systems. BIM can substantially reduce lead times and make the construction process more flexible and less wasteful. (Eastman 2008)

For S steel, the significant benefit is the coordination of the BIM models with AEC or other subcontractors. Autodesk Navisworks can be seen as the most functional BIM tool at files combination. Navisworks is not a modeling program, it links BIM 3D files into a Navisworks format (NWD) which is often a more useable file type than other formats.

Navisworks can run a schedule animation, sequencing animation, and clash detection. In this way, Navisworks has the ability to schedule the work flow of steel structure from start of prefabrication to finish of erection. The SDS/2 and CNC automation system cannot do the same job as Navisworks does.

The BIM model can bring many benefits to erection work. The BIM model is built from start of project when it has been designed at an architect’s office. This model can be directly used for steel erection. S Steel awards about 30 projects average per year including bridges and

building projects. Their field erection teams can work for most of their projects with the rest of them sold to other steel structure companies. The erection team cannot share the fabrication files at the same time. Jobsite orders or RFI were delayed or confused. These problems will be easily resolved by BIM. This is an important improvement for S Steel.

RFID Potential Usage

S Steel is using a barcode system as their steel member identification method. RFID system has been used in many industry fields. S Steel is ready for deployment of an RFID system. The major difference between Bar-code and RFID is the reading style and operation cost.

From field responses to bar-code use, they found that using bar-code is much better than using hand painting and chalk mark. But there are problems there, for example, the damage on the barcode, missing barcode, wrong placement, or delivery date mixed up. These problems can be avoided when using RFID. RFID can have data memory so that each sequence can read the same information. RFID tags are stronger than barcode and more durable for storing. RFID is easy tracking at storage and delivery when use GPS together. It can be checked by each member of the team to avoid the data comparison and delivery problems.

If RFID had been used from the start of design process, RFID and its data would flow down to the whole project. BIM can use RFID as its symbol so that every detailed part has its own identification number. It makes estimating and production easier.

Feasibility Analysis of BIM for S Steel Company

BIM can bring benefits to the engineering detailing and fabrication parts. BIM can improve the situation of S Steel. It makes the AEC plans easy to understand and avoids software conflicts. Navisworks can fit SDS/2 very well in both 3D CAD and steel connection details.

RFID labels members in a unique way for storage, delivery, and installation without confuses and mistakes. BIM uses RFID for data collection and retrieval that makes steel

structure construction accurate. Figure 6-12 shows the BIM flow for S Steel Construction in both fabrication and erection. It shows a view of the future job scope of S Steel. As a conclusion of the above analysis and BIM research for S Steel Company, BIM can definitely work for S Steel Company and bring more benefits to its workers and projects.

Example of S Steel Workflow Using BIM/RFID Framework

S Steel has automatic control machine using Computer Numerical Control (CNC) manufacture system. CNC manufacture system has a Function Block which is the key for collecting and executing operating orders and acting the machine.

The orders made by machining-feature-based design system are done by the same team with detailing and engineering design in the company. How do BIM tools link with CNC manufacture control system?

RFID as a digital data source can do a perfect linkage work. When the architect and engineer use BIM tools to design project, they can use the RFID system to label the steel components and assign information to the RFID tag that remains attached to it through the entire project. When the CNC machine makes the cut, the RFID represents the steel member. In this way, RFID works as information carrier. So the BIM/RFID Framework (BRF) can link the CNC system using the RFID system.

From the first activity shown in Figure 6-12, receiving the drawing, the BIM team creates 3D format Revit and Navisworks files with RFID used for the steel components. In this process, the 3D design software can use SDS/2 and Navisworks and the RFID coding system and database supports the decision making process. Biding and contractor document are printed out by the BIM office support system.

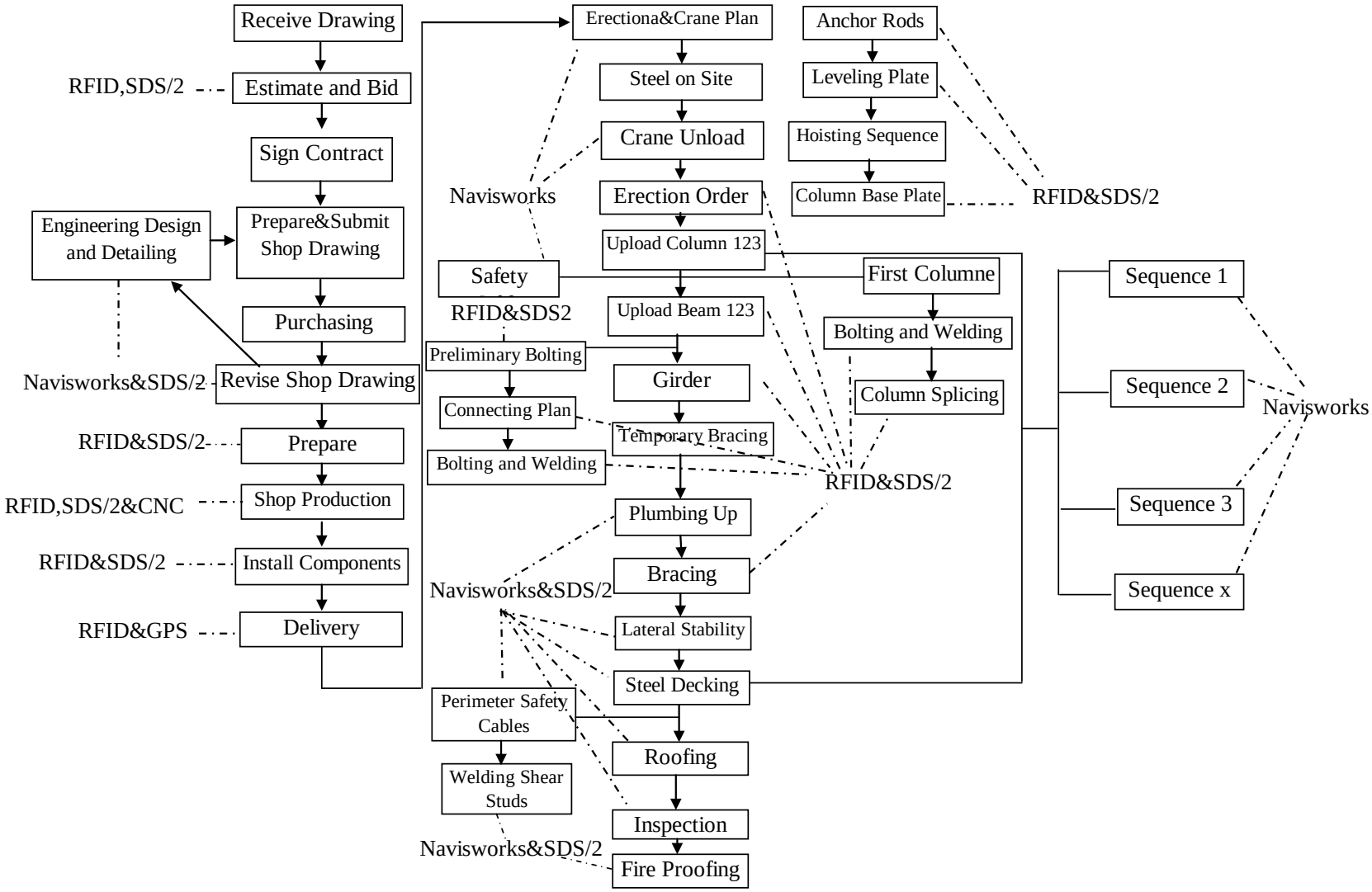


Figure 6-12. BIM work flow for S Steel fabrication and erection process

The decision-making system tests the benefits and others factors. If the bid is successful, the engineers and design department work with the BIM/RFID Framework. With the selected RFID, the BIM detailed drawings are created when running the design decision systems and RFID database.

In this process, the RFID database serves each steel component feature and design coding requirements to support the connection design. The design support system uses SDS/2 and Navisworks. The scheduling and planning job uses BDM to get the optimal erection plan. The process is: Steel components RFID group data are input into BIM testing. Then the results are output to the decision support systems to simulate and find an optimal plan. The shop work follows RFID members in detailing shop drawings.

The BIM/RFID Framework sends orders to the CNC manufacturing control system to cut the steel components. In this process, SDS2 and CNC control the manufacture, RFID acts as the shop drawing coding system. Other fabrication activities are all under the BIM/RFID Framework control when using the RFID coding system. The erection plan and processes have been discussed before. The Navisworks and SDS/2 are used as erection assistant systems for connection and welding work.

In this workflow, the Navisworks acts as a main 4D BIM software. Its functions for simulation and 4D visualization need to be improved. A strong functional software and fast computer hardware can support more BIM decision making model functions.

Time Based Supply Chain Management –On-time Delivery

Delivery is an important construction issue. This is critical for steel structures. Steel structures have better strength-to-weight ratio than other construction materials. They can be easily installed or dismantled. The build-up duration of steel structure buildings are normally much shorter than reinforced concrete structures. In this case study, most S Steel Company's

projects are over a million dollars. This gives them more pressure for on-time delivery because these projects are usually located in long distance. Schedules are very condensed on those projects as well. The supply chain management (SCM) is very important for S Steel and other parties on the project.

The cost based supply chain is the SCM major research field. But for fabricator and erector, the steel price fluctuates seasonally so that the steel suppliers have to change the contract prices. The time issue is more important because the special character of the fabricator. The fabricator needs a longer production time than the installation. The purchase orders need to be sent to mills. The shop drawings need to be detailed as soon as the contract is signed. The shop needs to get ready for cutting and drilling as soon as the materials come into storage. The welding and shop pre-assembling need to be ready as soon as the metal cutting work is done. The storage needs to be ready for receiving the raw steel materials, storing the finished members, then waiting for shipping. All these processes take time. In this case, delivery does not just begin from the storage's gate to the field's gate, but it actually begins from the day of signing the contract and ends till the members are installed.

RFID and GPS are perfectly suitable for those rush works. Manufacturing System Integration (MSI) associated with fabrication process and delivery process are based on the supply chain management (SCM) model. MSI integrated with BIM/RFID Framework has one important function, which is making decision on optimized supply plan to control the productive scheduling of fabrication and erection. Then BIM can reduce the design and production cycle-time and make the construction process less wasteful and more flexible.

Reminders can be set up on the BIM schedule. The BIM model can make an optimized time flow. For example, if a user make a schedule for erecting a group of members on December

1st, the critical date of the purchase order must be set on October 15th and the cutting must be ready between October 18th to 25th, the welding between October 19th to 27th, the painting between October 20th to 30th and delivery will between October 30 to December 1st. Also, the delivery weather, methods and roadmap will be shown on the delivery plan. The BIM/RFID Framework has a detailed work description, ready for the support documents and installation plan for each part of the activity.

Even the best schedule cannot predict some uncertain incidents. An example of that is the manufacturing facility that S Steel built the previous year. The steel erection schedule had to be extended by one month because of an equipment delay. This equipment was shipped from India. It took two months by ship o transport. An unexpected thing happened when it arrived to USA board. The shipping box of equipment was made of untreated wood and this is against the Custom regulation. The wood needs to be treated at someplace with equipment unloading. This took about two weeks for waiting on the treatment and re-boxed. It took another two weeks for transporting it to the loading place. This equipment needed to be put indoor and stay inside before the building envelope is finished so that it can be installed easier. All the steel erection and the successor tasks had to wait and were hence delayed.

Using the BIM/RFID Framework what could S Steel have done for this case? The system will also have a mode block that has all shipping information and Custom regulations. The BIM/RFID Framework will show a check list and request instructions for shipping either domestic or overseas. It will help avoid incidents and delays before they happen. Simulation testing for the shipping process may help in figuring out all uncertainty problems and delivery methods. Also, a rearranged plan may be found when using RFID location data and BIM schedule support system to define the work space.

Erection Sequence Analysis –Optimized Schedule

Construction phases are complex, characterized by a set of tasks or activities worked by different subcontractors. The erection sequences are separated by different operating cranes. Cranes are operated by different operators. The owner-contractor agreement may also contain a liquidated damage clause providing for compensatory damages due to delays. (AISC 1999)

Project schedules are based on an assumption of every party working at constant planning orders. But different parties have their own work style and quality. Cranes have varied conditions and weight limitations. Operators have skill levels and work abilities. All these differences require decisions in making an optimized plan and helping the project finish on time.

Steel erection jobs are usually separated by different sequences so that the user can schedule as many activities as they can. The traditional method of steel structure construction is to follow the original schedule from purchase order to delivery. If a job is delayed or its condition changed, the job site supervisor needs to file a RFI or RFC to the PM and GC's office, then to the fabricators. It takes at least two work days for a new schedule to be approved. It has to have storage spaces at the shop and the job site in case of any schedule changes affecting the fabricator or erector. The BIM/RFID Framework can adjust schedule in minutes, have real time jobsite feedback via the RFID system, and disseminate the schedule via the Internet. RFID is used as a control coding system for steel members. Its database has enough information for BIM decision making model to do optimal calculations and system support analysis. For example, after inputting RFID in a BIM model, using simulation and matrix calculation can make an optimal ranking of steel erection order.

It is happen some times waiting on jobsite when other work is blocking the sequence or working space accidentally. Through a BIM/RFID Framework, a jobsite zoning system may help arrange the space use and optimize those operations.

Figure 6-13 shows the work flow of a construction project. It compares the differences between the traditional project control methods and BIM/RFID Framework controlled projects. BIM design and simulation may save little time compared with traditional design methods. But the erection sequence saves much more time than traditional project organization methods when using the BIM control model. In addition, it eliminates the mistakes and confusion when reading old 2-D drawings, looking for right dimensions, or searching for connections or correct parts.

BIM decision model can bring three major benefits to AEC. The first benefit is the time saving for scheduling and planning. Figure 6-13 shows a big lap when using traditional methods for steel structure construction. The BIM/RFID Framework using the 4D real time control system gives erectors more flexible operating space and buffers for job arrangements between subcontractors. The second benefit is the space saving for steel storage. When using the BIM/RFID Framework, right-on-time designed system can minimize the needs for steel storage space either in the shop or on the jobsite. The third and biggest benefit is the effectiveness of using RFID as a key coding parameter, BIM with Total Quality Control (TQC) and Flexibility Production System (FPS) to highly improve the steel structure construction productivity.

TQC and FPS are smart IE (Intelligent Engineer) management technologies. CNC is one of these technologies too. The common character of these techniques is the intelligent ability of the machine or software control. Similar to the CNC system, it can automatically design the piece cutting plan in a given sheet of metal to have an optimized result for material saving.

By using the BIM database information, the design-decision-support system can be used to develop the best design result for shop workers. The design is even better than that done by very experienced users.

Current CPM and PERT schedule methods have a reschedule function. When any activity changes in the process of project, users need to reschedule to make sure all relational activities follow the change too. Then a new schedule is created. In the BIM decision making model, an automatic optimization schedule function can make for a better planning and safety environment.

Depending on these benefits, the BIM decision making model has the same intelligent functions in control and making decisions. They can improve the schedule details and perform real time sequences control for the job site. For the erection sequence, the BIM model can even make it possible for a short time cross sequences job arrangement.

In the framework of the BIM/RFID Framework, the schedule sequence is affected by almost all variable factors including building code, union rules, OSHA regulation, weather, time, cost, labor and quality. The change of project sequence not only impacts scheduling and planning, but also affect the job situation and condition.

The most important changes are focused on erection and crane plans. 4D BIM simulation and real time jobsite RFID control make the BIM/RFID Framework a feasible environment.

Figure 6-14 shows an animation of the structural steel erection process by sequence. The six sequences will slowly appear along with the working day in which hoisting of each sequence was completed. The last images to appear are of the masonry stair and elevator shafts. They were built after the frame was erected. The steel frame was connected to the vertical shafts to provide permanent lateral stability of the frame.

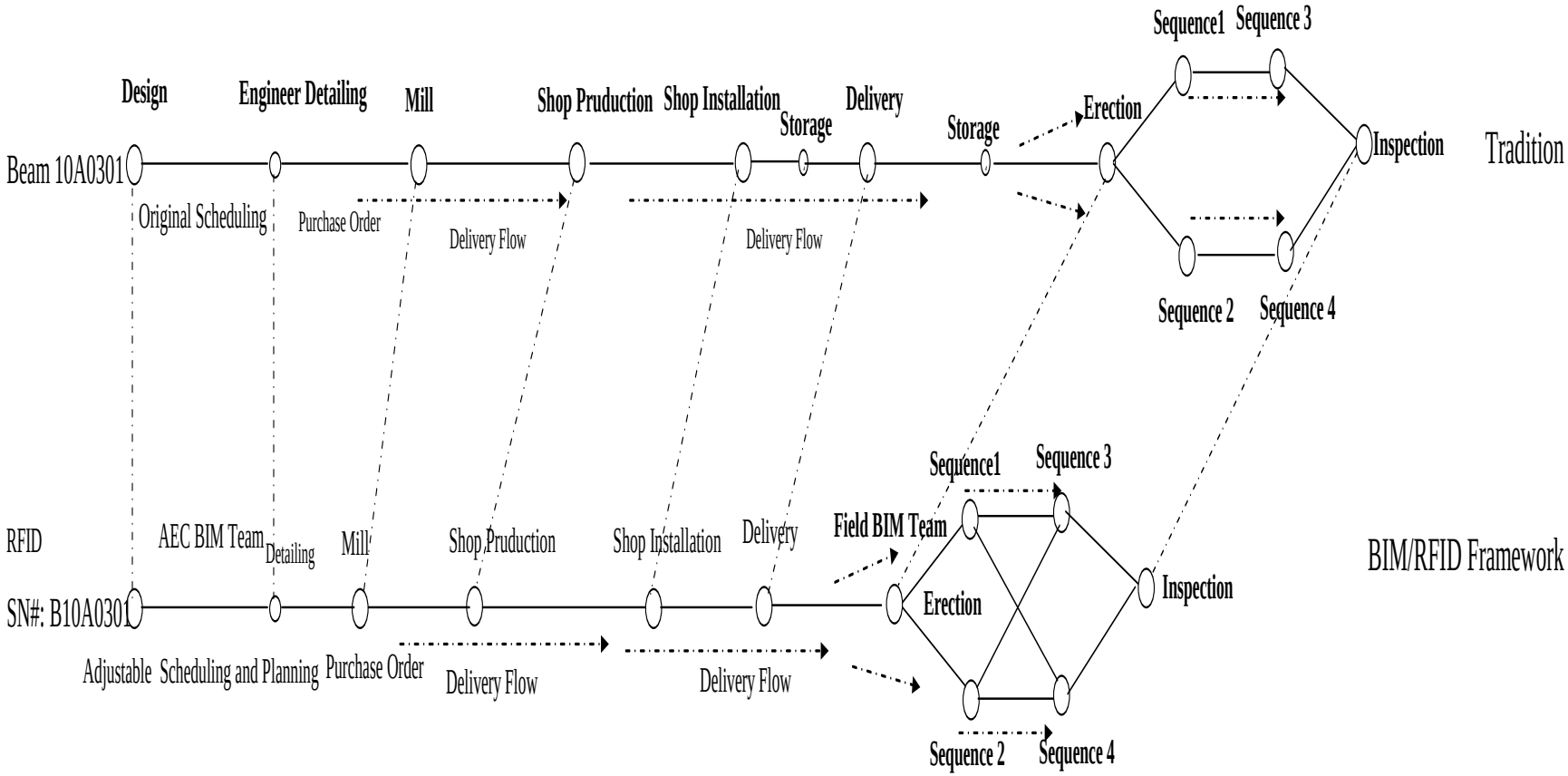


Figure 6-13. Tradition construction method versus BIM/RFID Framework schedule and delivery flow

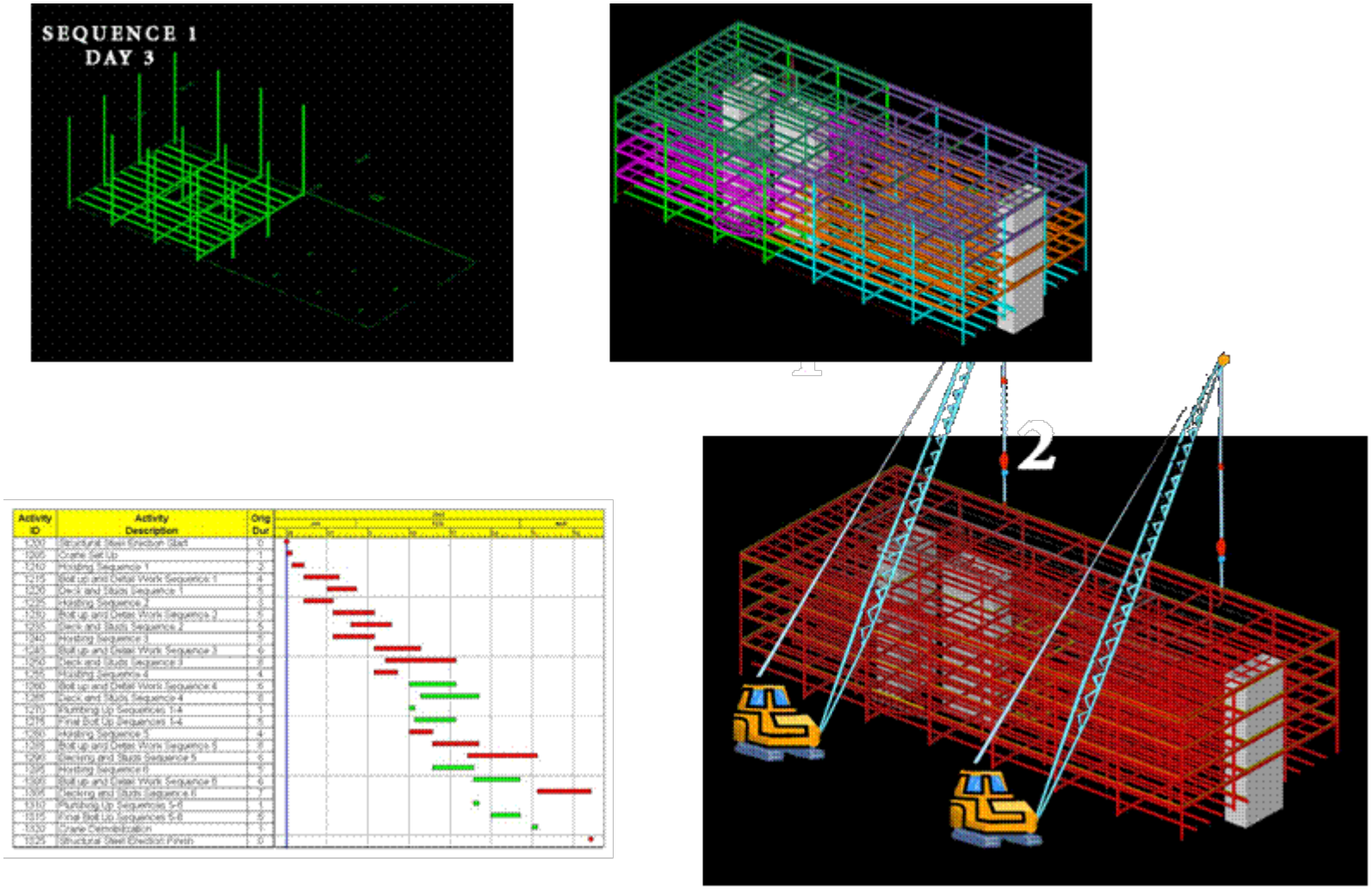


Figure 6-14. The simulation of BIM/RFID Framework operation for steel structure erection job sequences (AISC 2005)

Two crane locations were used for this project. Location 1 was used to erect sequences 1, 3, and 5. Location 2 was used to erect sequences 2, 4, and 6. The crane was moved to the appropriate location for each sequence. Crane locations were approximately 45 feet from the face of the building.

This is a detailed schedule of the erection process of the structural steel frame. In this project an average of 40 pieces of steel were hoisted per day. Hoisting, bolt up, detail work, decking and stud activities are performed by sequence. Hoisting consists of lifting and placing steel members into their appropriate position and temporarily fastening them using several bolts and/or welds. Plumbing up refers to the vertical alignment of the frame. Final bolt up refers to tightening the bolts which connect the components of the structure. (AISC 2005)

Using the BIM/RFID Framework can improve this program. All steel components are RFID tagged. From first day, it is clear that crew's work skill between sequences is different. By using the BIM/RFID Framework crane A finished 60 pieces of steel member when crane B only finished 40 pieces and one minor accidentally operation. Crane B responds for sequence 2, 4 and 6 which is east parts floor 1 and floor 3, west side floor 2 which cross over with crane A's work zone. Here is a problem. The original schedule designed for crane A and B is for the average same workloads. In this case, crane B would be far more delay than crane A. It is possible to delay the whole project if the current process is kept. This situation is normal and was hard to solve before, because of the BIM/RFID model the situation is improved.

The RFID tag gives the real-time jobsite information to the 4D BIM/RFID Framework. It makes it easy to control the sequence erection by pieces. The erection plan can follow the RFID marked 4D BIM/RFID Framework to adjust the erection member sequence in a safe and short time. By timing the two crane progress, the crane erection plan can be flexible for changes. The

changes come from two parts. One is the erection order, another is planning change. The erection order change can help crane B do easy the hoisting while crane A can handle most of the hard members. Planning change can make follow up activity ready for the possible work change for whatever time or work zone. The RFID 4D BIM/RFID Framework can make these changes more correctly and smoothly.

Summary

The BIM/RFID Framework has three main parts. The very first part is the database, its information comes from many resources and its needs to be retrieved using a convenient filter system so that users can have information that they really want and not be bothered by a lot of data.

The BIM/RFID Framework has to have data transaction and dialog integration functions compatible with different software and functions integration. A model typically may changes many times prior to creating the construction documentation. Linking models prevents the accidental editing, moving, or deleting of model elements built by the design team. Autodesk Navisworks has the most robust tool in which these models are compiled and tested. Using the Coordination Review tool in Revit is another effective way of letting a BIM user knows whether linked elements have been shifted during use or because of updates (Hardin 2009).

The BIM/RFID Framework from the designer helps in detailing items and scoping them as well as coordinating owner-driven design and program shifts. The BIM team can use a BIM pit or BIM huddle to help the owner who has a fast-track project in using BIM to find a way to rapidly advance a project. In this case, the BIM team at jobsite office can have members work together to model and virtually construct the proposed structure. Autodesk Integrated project delivery (IPD) is one of the emerging standards for early collaboration and effective decision making in the building industry. IPD has compatibility condition for all Autodesk software so

that the BIM decision model can develop a project management function for the whole project instead of the design and simulation phase only.

The key module for implementing the model is decision-making tools. Decision Tree and other statistic tools are using to analyze and verify the data which can support management team making decision. The RFID, GPS and web-transaction technique are used to develop a real-time 4D erection jobsite BIM/RFID Framework. RFID is the key of real time 4D jobsite control too. It not only gives the steel members identification, but also connected detailing data of steel members with BIM Model. In this case, RFID marks every detail change relative to BIM/RFID Framework and results in BIM data updating whenever steel member data are changed.

In developing a real-time BIM 4D model by using RFID, there are still some barriers from network technology, 4D software, RFID tags, data formatting and transferring. Current wireless network barcode readers have many limitations for effective data transferring. RFID reading data are not easily transferred to central computers. The Wi-Fi maybe an answer for this problem, but it needs to have an Internet system support. 4D tools such as Navisworks and Vico have 4D functionality but do not support real-time function. RFID tag needs special material for use on steel members so that RFID can adhere to the surface of steel stably and firmly without any damages. RFID data format and transfers are still argued by researcher and field personnel because there is no proper equipment available. The PDA has been used for some testing projects, but it just acts as a barcode scanner not a RFID scanner. This process can only deliver a daily update but not real-time simulation.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

Research Summary and Contribution

This research proposes a model that combines web-based four dimensional (4D), Building Information Modeling (BIM), Radio Frequency Identification (RFID) and Manufacturing Systems Integration (MSI). The model focuses on steel fabrication and site steel erection. The program is based on a multi-purpose model, which uses RFID plus steel series-code and color-codes systems to differentiate between steel pieces, to help control the schedule of a project, and to describe the entire scope of construction. It relies on a 3D graphic scheduling to display real-time steel erection. It helps with planning jobs, verifying erection information, controlling job sequence, site inspection, and other field related jobs. This BIM/RFID Framework also has more functions on helping AEC to make decisions by using the progress shown on the BIM control and testing system.

Building Information Modeling (BIM) with four dimensional (4D) technologies and Manufacturing Systems Integration (MSI) make it possible to develop an effective design-planning-fabrication-erection intranet-based system. The significance of this model is to help to minimize project mistakes. This model deals with uncertainty problems, which is the area that needs a lot of investigation. If project managers can view the current project situation and predict the possible results in a simulation environment, it will be easy for them to control the changes and avoid the risks. In addition, project managers can find out solutions to deal with the possible mistakes or errors. The BIM/RFID Framework is based on a data base and a model base. The retrieval of useful and accurate data gives the decision maker the possibility of making optimized decision. Testing was used to verify the feasibility of the model.

Limitations and Barriers of the BIM/RFID Framework

Database Problems

Many functions have been developed in BIM research which is based on different database systems. But current construction databases are too simple to support these functions in working properly. Each BIM tool has its own data resource when it is developed on a case by case basis. Unfortunately, even these databases are not open to the public.

Data mining technology is also a limitation to the BIM/RFID Framework functionality. Data retrieval becomes a problem when decision-support system needs qualified data to make decision. Either useless data retrieved or too many data elements to work on to make a choice confuse users. In this case, data mining technique needs to be improved for the quality of data supply and data retrieval.

Lack of data access

Lack of data is a critical limitation for construction industry to use BIM functions. This limitation has two reasons: one is because the data accumulation needs time; another reason is because data security and copyrights limit database general use by different parties.

Data safety problem

The concern of data safety has limited BIM development as well. This is because of the nature of the construction industry. General contractors control the whole project and give orders to subcontractor to finish their jobs. When BIM is used for a project, subcontractors are legally using BIM resource and reading project information from the same BIM environment and systems. This brings a problem for data safety and user limitations.

Current BIM tools rarely treat this problem in their functional design. BIM projects are controlled by consulting team members or the PM team, subcontractors are allowed to use BIM tools to review detail project information only if they come to PM office. In this case, BIM only

has partial AEC use and its access is limited for subcontractors. This is a big barrier for BIM usage.

Data reliability

BIM tools are marketed by different companies, designers, programmers, and developing software. Navisworks is a main BIM tool for project control but they still need Timberline for estimating, Primavera Project Planning or Microsoft Project for scheduling, and Tekla or CIS/2 for detail steel connections, all these program may have some conflicts as well. Navisworks is able to access different data file formats.

Visualization Quality Transaction and Transfer Confliction

BIM tools have functions of 3D and 4D imaging. But the imaging has no good quality for transaction and transferred imaging. Decision support systems support the model structure and make sure the model is going into the right direction. Using RFID with BIM for the structural steel project is still a new research field. Despite the power and availability of 3D/4D tools, their use is still not common in most areas of design and construction (Issa 2003). 4D is still not a widely accepted design/construction tool in the construction industry.

Field Operations Internet and Network Limitation

The performance speed of on site computers also depends on the speed of Internet and the hardware involved. The visualization sensor and virtual navigation controllers need to be reconsidered to fit data entry and information tracking. The job environment also limits the use of network connection on jobsite computers, especially for remote projects. The BIM tools environment and their technical capabilities also need to be improved. In this situation, network connection techniques and jobsite intranet functions also need to be improved. WI-FI works fine at a normal job site, but for a larger jobsite a set receiver and transmitter is needed to hold the data and transfer it to a wired computer which is connected with the BIM control center.

Safety Control Still Depends on Human Responsibility

For a long time, researchers have wanted to have a computer system to control jobsite safety so that workers can work at a hazards free working space. BIM tools can link with the safety database and have functions like safety tracking and jobsite protection system, but they still need responsible humans to maintain them. This problem gives the BIM/RFID Framework some potential uncertainty results after a decision had been made. All the aforementioned problems and barriers can affect the result of the BIM/RFID Framework. In other words, the BIM/RFID Framework is based on a reasonable result of statistic probability guessing and technique calculation.

Recommendations for Future Research

The future development work for this research will include simplifying and standardizing the BIM 4D operations so that various resources can be linked and displayed correctly without conflicts or errors. Furthermore, the web-based 4D visualization system has huge imaging files. It is usually too large to transfer in the field. It is still a problem for data transfer between AEC offices to jobsite office. (see Figure 7-1)

GIS and GPS have been used on construction projects for a while, but there is no corresponding program to link them with BIM. The future of GIS developments relative to BIM functions requires GIS to have a detailed material database in layers which include BIM components and structure information. RFID and 4D BIM can give improved performance if future improved GIS and GPS systems can assist RFID in locating in real time structural steel members.

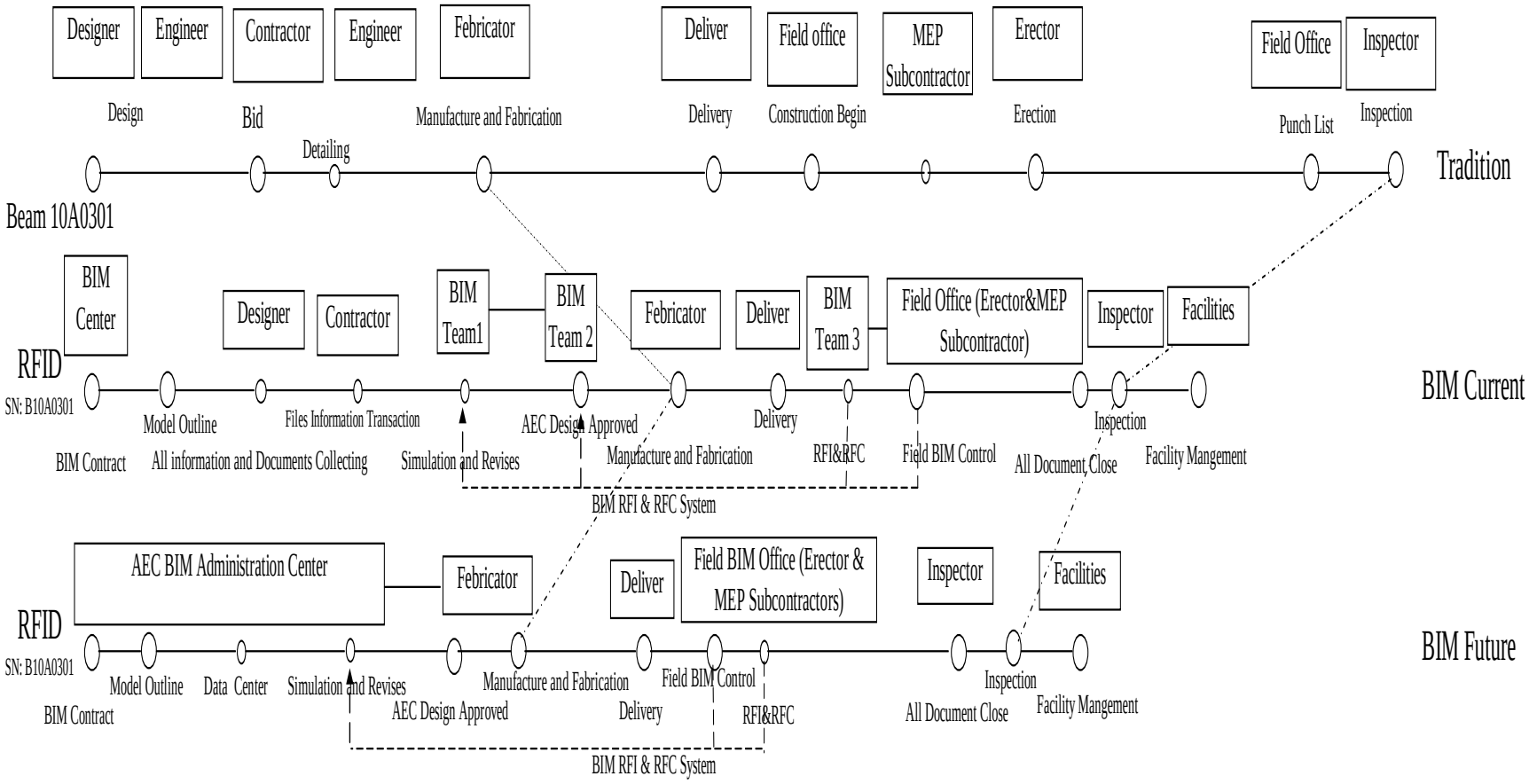


Figure 7-1. Traditional construction versus BIM current and future planning and organization

Robotically site layout will also be a very interesting future research topic. It should directly display BIM images from the simulation model picture to the real world. On the other hand, a 3D image could also be built up by scanning an existing building so that users can have a direct 3D model when the original building documents are lost.

Finally, data mining and information retrieval techniques still need more improvements and advancement to make the decision information system more powerful. RFID database can be use as linkage of projects so that followed similar projects can find a better solution for unexpected problems. A smart coding system is developing for better data mining and data retrieval solutions. In a near future, BIM database may be opened and used by more construction companies and projects.

APPENDIX A
SAFETY STANDARDS FOR CONSTRUCTION WORK

(Washington State Dept. of Labor and Industries)

Chapter 296-155 WAC Part P Construction Work Steel Erection

PART P
STEEL ERECTION

WAC 296-155-701 Scope.

(1) (a) This part applies to employers involved in the construction, alteration and repair of single or multistory buildings, bridges, and a variety of other structures. This part applies to employers involved in steel erection unless specifically excluded.

(b) Examples of steel erection structures include, but are not limited to:

Aerialways;	Aerospace facilities and structures;
Air and cable supported structures;	Amphitheaters;
Amusement park structures and rides;	Aqueducts;
Artistic and monumental structures;	Atriums;
Auditoriums;	Balconies;
Billboards;	Bins;
Bridges;	Canopies;
Car dumpers;	Catwalks;
Chemical process structures;	Conveyor supports and related framing;
Conveyor systems;	Cranes and craneways;
Curtain walls;	Draft curtains;
Elevator fronts;	Energy exploration structures;
Energy production, transfer and storage structures and facilities;	Entrances;
Fire containment structures;	Fire escapes;
Furnaces;	Geodesic domes;
Hi-bay structures;	Hoppers;
Industrial structures;	Lift slab/tilt-up structures;
Light towers;	Malls;
Metal roofs;	Mills;
Monorails;	Ovens;
Overpasses;	Penthouses;
Platforms;	Power plants;
Racks and rack support structures and frames;	Radar and communication structures;

WAC 296-155-701 (Cont.)

Rail, marine and other transportation structures;	Scoreboards;
Signage;	Single and multistory buildings;
Skylights;	Sound barriers;
Space frames;	Stackers/reclaimers;
Stacks;	Stadiums;
Stair towers;	Stairways;
Store fronts;	Systems-engineered metal buildings;
Trestles;	Underpasses;
Viaducts;	Water process and water containment structures; and
Window walls.	

(2) (a) Covered steel erection work includes the:

- Hoisting, laying out, placing, connecting, welding, burning, guying, bracing, bolting, plumbing and rigging of structural steel, steel joists, and metal buildings; and
- Installing metal decking, curtain walls, window walls, siding systems, miscellaneous metals, ornamental iron and similar materials.

(b) The following work is also covered by this part when done during, and are a part of, steel erection work:

Anchoring devices;	Building equipment;
Building specialties;	Cable stays;
Castings;	Cold formed steel framing;
Column covers;	Conveying systems;
Crane rails and accessories;	Detention or security equipment and doors, windows and hardware;
Doors; windows;	Elevator beams;
Enclosures and pockets;	Falsework for temporary supports of permanent steel members;
Fascias;	Fences and gates;
Ferrous metals and alloys;	Floor plates;
Gaskets;	Glass;
Gratings;	Grillage;

WAC 296-155-701 (Cont.)

Handrails;	Hardware;
Hydraulic structures;	Joint fillers;
Ladders;	Louvers;
Metal decking and raceway systems and accessories;	Metal panels and panel wall systems;
Metal roofing and accessories;	Metal siding; bridge flooring;
Miscellaneous, architectural and ornamental metals and metal work;	Multipurpose supports;
Nonferrous metals and alloys;	Ornamental iron work, expansion control including bridge expansion joint assemblies;
Penthouse enclosures;	Perforated metals;
Permanent and temporary bents and towers;	Plastics and synthetic composite materials;
Railings;	Rigging, hoisting, laying out, placing, connecting, guying, bracing, dismantling, burning, welding, bolting, grinding, sealing, caulking, and all related activities for construction, alteration and/or repair of materials and assemblies such as structural steel;
Safety systems for steel erection;	Sealants and seals;
Sheet metal fabrications;	Shelf racks;
Skylights;	Slide bearings;
Soffit panels;	Stairs;
Steel and metal joists;	Stone and other nonprecast concrete architectural materials mounted on steel frames;
Structural cabling;	Structural metal framing and related bracing and assemblies; and
Trench covers.	

(3) Controlling contractor duties are specified in WAC 296-155-703 (1) and (3), 296-155-707 (2)(b), 296-155-714(2), and 296-155-716(5).

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-36), § 296-155-701, filed 06/19/02, effective 09/01/02].

WAC 296-155-702 Definitions.

Anchored bridging means that the steel joist bridging is connected to a bridging terminus point.

Bolted diagonal bridging means diagonal bridging that is bolted to a steel joist or joists.

Bridging clip means a device that is attached to the steel joist to allow the bolting of the bridging to the steel joist.

WAC 296-155-702 (Cont.)

Bridging terminus point means a wall, a beam, tandem joists (with all bridging installed and a horizontal truss in the plane of the top chord) or other element at an end or intermediate point(s) of a line of bridging that provides an anchor point for the steel joist bridging.

Choker means a wire rope or synthetic fiber rigging assembly that is used to attach a load to a hoisting device.

Cold forming means the process of using press brakes, rolls, or other methods to shape steel into desired cross sections at room temperature.

Column means a load-carrying vertical member that is part of the primary skeletal framing system. Columns do not include posts.

Competent person (also defined in WAC 296-155-012) means one who can identify existing or predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization or authority by nature of their position to take prompt corrective measures to eliminate them. The person must be knowledgeable of the requirements of this part.

Connector means someone who, working with hoisting equipment, is placing and connecting structural members and/or components.

Constructibility means the ability to erect structural steel members in accordance with this part without having to alter the overall structural design.

Construction load (for joist erection) means any load other than the weight of the employee(s), the joists and the bridging bundle.

Controlled load-lowering means lowering a load by means of a mechanical hoist drum device that allows a load to be lowered with maximum control using the gear train or hydraulic components of the hoist mechanism. Controlled load lowering requires the use of the hoist drive motor, rather than the load hoist brake, to lower the load.

Controlling contractor means a prime contractor, general contractor, construction manager or any other legal entity that has the overall responsibility for the construction of the project--its planning, quality and completion.

Critical lift means a lift that:

- Exceeds seventy-five percent of the crane or derrick rated load chart capacity; or
- Requires the use of more than one crane or derrick.

Derrick floor means an elevated floor of a building or structure that has been designated to receive hoisted pieces of steel prior to final placement.

Double connection means an attachment method where the connection point is intended for two pieces of steel that share common bolts on either side of a central piece.

Double connection seat means a structural attachment that, during the installation of a double connection, supports the first member while the second member is connected.

Employee (and other terms of like meaning, unless the context of the provision containing such a term indicates otherwise) means an employee of an employer who is employed in the business of his or her employer whether by way of manual labor or otherwise and every person in this state who is engaged in the employment of or who is working under an independent contract the essence of which is personal labor for an employer under this standard whether by way of manual labor or otherwise.

WAC 296-155-702 (Cont.)

Employer means any person, firm, corporation, partnership, business trust, legal representative, or other business entity which engages in any business, industry, profession, or activity in this state and employs one or more employees or who contracts with one or more persons, the essence of which is the personal labor of such person or persons and includes the state, counties, cities, and all municipal corporations, public corporations, political subdivisions of the state, and charitable organizations: Provided, That any persons, partnership, or business entity not having employees, and who is covered by the Industrial Insurance Act must be considered both an employer and an employee.

Erection bridging means the bolted diagonal bridging that is required to be installed prior to releasing the hoisting cables from the steel joists.

Final interior perimeter means the perimeter of a large permanent open space within a building such as an atrium or courtyard. This does not include openings for stairways, elevator shafts, etc.

Floor hole (decking hole) means an opening measuring less than twelve inches but more than one inch in its least dimension in any floor, roof, or platform through which materials but not persons may fall, such as a belt hole, pipe opening, or slot opening.

Girt (in systems-engineered metal buildings) means a "Z" or "C" shaped member formed from sheet steel spanning between primary framing and supporting wall material.

Headache ball means a weighted hook that is used to attach loads to the hoist load line of the crane.

Hoisting equipment means lifting equipment designed to lift and position a load of known weight to a location at some known elevation and horizontal distance from the equipment's center of rotation. Hoisting equipment includes, but not limited to:

- Cranes;
- Derricks;
- Tower cranes;
- Barge-mounted derricks or cranes;
- Gin poles; and
- Gantry hoist systems.

Note: A come-a-long (a mechanical device, usually consisting of a chain or cable attached at each end, that is used to facilitate movement of materials through leverage) is not considered hoisting equipment.

Metal decking means a commercially manufactured, structural grade, cold rolled metal panel formed into a series of parallel ribs and includes metal floor and roof decks, standing seam metal roofs, other metal roof systems and other products such as bar gratings, checker plate, expanded metal panels, and similar products. After installation and proper fastening, these decking materials serve a combination of functions including: A structural element designed in combination with the structure to resist, distribute and transfer loads, stiffen the structure and provide a diaphragm action; a walking/working surface; a form for concrete slabs; a support for roofing systems; and a finished floor or roof.

Multiple lift rigging means a rigging assembly manufactured by wire rope rigging suppliers that facilitates the attachment of up to five independent loads to the hoist rigging of a crane.

Must means mandatory.

Permanent floor means a structurally completed floor at any level or elevation (including slab on grade).

WAC 296-155-702 (Cont.)

Post means a structural member with a longitudinal axis that is essentially vertical, that:

- Weighs three hundred pounds or less and is axially loaded (a load presses down on the top end); or
- Is not axially loaded, but is laterally restrained by the above member. Posts typically support stair landings, wall framing, mezzanines and other substructures.

Project structural engineer of record means the registered, licensed professional responsible for the design of structural steel framing and whose seal appears on the structural contract documents.

Purlin (in systems-engineered metal buildings) means a "Z," "C," or "W" shaped member formed from sheet steel spanning between primary framing and supporting roof material.

Qualified person means one who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training, and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter, the work, or the project.

Safety deck attachment means an initial attachment that is used to secure an initially placed sheet of decking to keep proper alignment and bearing with structural support members.

Shear connector means headed steel studs, steel bars, steel lugs, and similar devices which are attached to a structural member for the purpose of achieving composite action with concrete.

Steel erection means the construction, alteration or repair of steel buildings, bridges and other structures, including the installation of metal decking and all planking used during the process of erection.

Steel joist means an open web, secondary load-carrying member of one hundred forty-four feet (43.9 m) or less, designed by the manufacturer, used for the support of floors and roofs. This does not include structural steel trusses or cold-formed joists.

Steel joist girder means an open web, primary load-carrying member, designed by the manufacturer, used for the support of floors and roofs. This does not include structural steel trusses.

Steel truss means an open web member designed of structural steel components by the project structural engineer of record. For the purposes of this subpart, a steel truss is considered equivalent to a solid web structural member.

Structural steel means a steel member, or a member made of a substitute material (such as, but not limited to, fiberglass, aluminum or composite members). These members include, but are not limited to, steel joists, joist girders, purlins, columns, beams, trusses, splices, seats, metal decking, girts, and all bridging, and cold formed metal framing which is integrated with the structural steel framing of a building.

Systems-engineered metal building means a metal, field-assembled building system consisting of framing, roof and wall coverings. Typically, many of these components are cold-formed shapes. These individual parts are fabricated in one or more manufacturing facilities and shipped to the job site for assembly into the final structure. The engineering design of the system is normally the responsibility of the systems-engineered metal building manufacturer.

Tank means a container for holding gases, liquids or solids.

You means the employer.
[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-36), § 296-155-702, filed 06/19/02, effective 09/01/02].

WAC 296-155-703 Site layout, site-specific erection plan and construction sequence.

(1) Before steel erection work can start the controlling contractor must ensure the steel erector is provided written notifications that:

(a) The concrete in the footings, piers and walls and the mortar in the masonry piers and walls has attained either:

- Seventy-five percent of the intended minimum compressive design strength; or
- Sufficient strength to support the loads imposed during steel erection.

The basis of these measurements is the appropriate ASTM standard test method of field cured samples.

(b) Any repairs, replacements and modifications to the anchor bolts were done per WAC 296-155-707(2).

(2) The steel erector must receive written notice that the concrete in the footings, piers and walls or the mortar in the masonry piers and walls has attained, on the basis of an appropriate ASTM standard test method of field-cured samples, either seventy-five percent of the intended minimum compressive design strength or sufficient strength to support the loads imposed during steel erection.

(3) **Site layout.** The controlling contractor must ensure that the following is provided and maintained:

(a) Adequate access roads into and through the site for the safe delivery and movement of derricks, cranes, trucks, other necessary equipment, and the material to be erected and means and methods for pedestrian and vehicular control.

Exception: *This requirement does not apply to roads outside the construction site.*

(b) A firm, properly graded, drained area, readily accessible to the work with adequate space for the safe storage of materials and the safe operation of the erector's equipment.

(4) **Preplanning of overhead hoisting operations.** All hoisting operations in steel erection must be preplanned to ensure that the requirements of WAC 296-155-704(4) are met.

(5) **Site-specific erection plan.** Where employers elect, due to conditions specific to the site, to develop alternate means and methods that provide employee protection in accordance with WAC 296-155-704 (3)(e), 296-155-709 (1)(d) or (5)(d), a site-specific erection plan must be developed by a qualified person and be available at the worksite. Guidelines for establishing a site-specific erection plan are contained in Appendix A to this part.

(6) Steel erection must be done under the supervision of a competent person who is present at the worksite.
[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-36), § 296-155-703, filed 06/19/02, effective 09/01/02].

WAC 296-155-704 Hoisting and rigging.

(1) All the provisions of WAC 296-155-525 and 296-155-526 apply to hoisting and rigging.

(2) In addition, subsections (3) through (5) of this section apply regarding the hazards associated with hoisting and rigging.

WAC 296-155-704 (Cont.)

(3) **General.**

(a) Crane preshift visual inspection.

(i) Cranes being used in steel erection activities must be visually inspected prior to each shift by a competent person. The inspection must include observation for deficiencies during operation and, as a minimum, must include:

- All control mechanisms for maladjustments;
- Control and drive mechanism for excessive wear of components and contamination by lubricants, water or other foreign matter;
- Safety devices, including boom angle indicators, boom stops, boom kick out devices, anti-two block devices, and load moment indicators where required;
- Air, hydraulic, and other pressurized lines for deterioration or leakage, particularly those which flex in normal operation;
- Hooks and latches for deformation, chemical damage, cracks, or wear;
- Wire rope reeving for compliance with hoisting equipment manufacturer's specifications;
- Electrical apparatus for malfunctioning, signs of excessive deterioration, dirt, or moisture accumulation;
- Hydraulic system for proper fluid level;
- Tires for proper inflation and condition;
- Ground conditions around the hoisting equipment for proper support, including ground settling under and around outriggers, ground water accumulation, or similar conditions;
- The hoisting equipment for level position; and
- The hoisting equipment for level position after each move and setup.

(ii) If any deficiency is identified, an immediate determination must be made by the competent person if the deficiency constitutes a hazard.

(iii) If the deficiency constitutes a hazard, the hoisting equipment must be removed from service until the deficiency has been corrected.

(iv) The operator is responsible for those operations under their direct control. Whenever there is any doubt as to safety, the operator must have the authority to stop and refuse to handle loads until safety has been assured.

(b) A qualified rigger (a rigger who is also a qualified person) must inspect the rigging prior to each shift in accordance with WAC 296-155-330.

(c) The headache ball, hook or load must not be used to transport personnel, except as provided in (d) of this subsection.

(d) Cranes or derricks may be used to hoist employees on a personnel platform when work under this part is being conducted if all the provisions of WAC 296-155-525 through 296-155-528 are met.

(e) Safety latches on hooks must not be deactivated or made inoperable except:

WAC 296-155-704 (Cont.)

(i) When a qualified rigger has determined that the hoisting and placing of purlins and single joists can be performed more safely by doing so; or

(ii) When equivalent protection is provided in a site-specific erection plan.

(4) **Working under loads.**

(a) Routes for suspended loads must be preplanned to ensure that no employee works directly below a suspended load except when:

(i) Engaged in the initial connection of the steel; or

(ii) Necessary for the hooking or unhooking of the load.

(b) When working under suspended loads, the following criteria must be met:

(i) Materials being hoisted must be rigged to prevent unintentional displacement;

(ii) Hooks with self-closing safety latches or their equivalent must be used to prevent components from slipping out of the hook; and

(iii) All loads must be rigged by a qualified rigger.

(5) **Multiple lift rigging procedure.**

(a) A multiple lift must only be performed if the following criteria are met:

- A multiple lift rigging assembly is used;
- A multiple lift is only permitted when specifically within the manufacturer's specifications and limitations;
- A maximum of five members are hoisted per lift;

Exception: *Bundles of decking must not be lifted using the multiple lift rigging procedure, even though they meet the definition of structural members in WAC 296-155-702.*

- Only beams and similar structural members are lifted; and
- All employees engaged in the multiple lift have been trained in these procedures in accordance with WAC 296-155-717 (3)(a).

(b) Components of the multiple lift rigging assembly must be specifically designed and assembled with a maximum capacity for total assembly and for each individual attachment point. This capacity, certified by the manufacturer or a qualified rigger, must be based on the manufacturer's specifications with a five to one safety factor for all components.

(c) The total load must not exceed:

- The rated capacity of the hoisting equipment specified in the hoisting equipment load charts; and
- The rigging capacity specified in the rigging-rating chart.

WAC 296-155-704 (Cont.)

(d) The multiple lift rigging assembly must be rigged with members:

- Attached at their center of gravity and maintained reasonably level;
- Rigged from top down; and
- Rigged at least seven feet (2.1 m) apart.

(e) The members on the multiple lift rigging assembly must be set from the bottom up.

(f) Controlled load lowering must be used whenever the load is over the connectors.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-36), § 296-155-704, filed 06/19/02, effective 09/01/02]. Statutory Authority: RCW 49.17.010, .040, .050, and .060. 06-05-027 (Order 05-45), § 296-155-704, filed 02/07/06, effective 04/01/06.

WAC 296-155-706 Structural steel assembly.

(1) Structural stability must be maintained at all times during the erection process.

- Make sure that multistory structures have the following:

  - Permanent floors installed as the erection of structural members progress;
  - No more than eight stories between the erection floor and the upper-most permanent floor; and
  - No more than four floors or forty-eight feet (14.6 m), whichever is less, of unfinished bolting or welding above the foundation or uppermost permanent secured floor.

Exception: *The above applies except where the structural integrity is maintained as a result of design.*

(2) **Walking/working surfaces.**

(a) Shear connectors and other similar devices.

(i) Shear connectors, reinforcing bars, deformed anchors or threaded studs must not be attached to the top flanges of beams, joists or beam attachments so they project vertically from or horizontally across the top flange of the member until after the metal decking, or other walking/working surface has been installed. This becomes a tripping hazard. Examples of shear connectors are headed steel studs, steel bars or steel lugs.

(ii) Installation of shear connectors on composite floors. When shear connectors are used in construction of composite floors, roofs and bridge decks, employees must lay out and install the shear connectors after the metal decking has been installed, using the metal decking as a working platform.

(b) Slip resistance of metal decking. (Reserved.)

(c) Reserved.

(d) Safe access must be provided to the working level. Employees must not slide down ropes, columns, or ladders.

(3) **Plumbing-up.**

(a) When deemed necessary by a competent person, plumbing-up equipment must be installed in conjunction with the steel erection process to ensure the stability of the structure.

WAC 296-155-706 (Cont.)

(b) When used, plumbing-up equipment must be in place and properly installed before the structure is loaded with construction material such as loads of joists, bundles of decking or bundles of bridging.

(c) Plumbing-up equipment must be removed only with the approval of a competent person.

(4) **Metal decking.**

(a) Hoisting, landing and placing of metal decking bundles.

(i) Bundle packaging and strapping must not be used for hoisting unless specifically designed for that purpose.

(ii) If loose items such as dunnage, flashing, or other materials are placed on the top of metal decking bundles to be hoisted, such items must be secured to the bundles.

(iii) Bundles of metal decking on joists must be landed in accordance with WAC 296-155-709 (5)(d).

(iv) Metal decking bundles must be landed on framing members so that enough support is provided to allow the bundles to be unbanded without dislodging the bundles from the supports.

(v) At the end of the shift or when environmental or job site conditions require, metal decking must be secured against displacement.

(b) Roof and floor holes and openings. Metal decking at roof and floor holes and openings must be installed as follows:

(i) Framed metal deck openings must have structural members turned down to allow continuous deck installation except where not allowed by structural design constraints or constructibility.

(ii) Roof and floor holes and openings must be decked over. Where large size, configuration or other structural design does not allow openings to be decked over (such as elevator shafts, stair wells, etc.) employees must be protected in accordance with chapter 296-155 WAC, Part C-1 or Part K.

(iii) Metal decking holes and openings must not be cut until immediately prior to being permanently filled with the equipment or structure needed or intended to fulfill its specific use and which meets the strength requirements of (c) of this subsection, or must be immediately covered.

WAC 296-155-706 (Cont.)

(c) **Covering roof and floor openings.** Smoke domes or skylight fixtures that have been installed are not considered covers for the purpose of this section unless they meet the strength requirements of WAC 296-155-505 (4)(g) (Part K).

(d) **Decking gaps around columns.** Wire mesh, exterior plywood, or equivalent, must be installed around columns where planks or metal decking do not fit tightly. The materials used must be of sufficient strength to provide fall protection for personnel and prevent objects from falling through.

(e) **Installation of metal decking.**

(i) Metal decking must be laid tightly and immediately secured upon placement to prevent accidental movement or displacement.

(ii) During initial placement, metal decking panels must be placed to ensure full support by structural members.

(f) **Derrick floors.**

(i) A derrick floor must be fully decked and or planked and the steel member connections completed to support the intended floor loading.

(ii) Temporary loads placed on a derrick floor must be distributed over the underlying support members so as to prevent local overloading of the deck material.

[Statutory Authority: RCW 49.17.010, .020, .040, .050, and .060. 07-03-163 (Order 06-30), § 296-155-706, filed 01/24/07, effective 04/01/07. Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-706, filed 06/19/02, effective 09/01/02].

WAC 296-155-707 Column anchorage.

(1) **General requirements for erection stability.**

(a) All columns must be anchored by a minimum of four anchor rods (anchor bolts).

(b) Each column anchor rod (anchor bolt) assembly, including the column-to-base plate weld and the column foundation, must be designed to resist a minimum eccentric gravity load of three hundred pounds (136.2 kg) located eighteen inches (.46 m) from the extreme outer face of the column in each direction at the top of the column shaft.

(c) Columns must be set on level finished floors, pregrouted leveling plates, leveling nuts, or shim packs which are adequate to transfer the construction loads.

(d) All columns must be evaluated by a competent person to determine whether guying or bracing is needed; if guying or bracing is needed, it must be installed.

(2) **Repair, replacement or field modification of anchor rods (anchor bolts).**

(a) Anchor rods (anchor bolts) must not be repaired, replaced or field-modified without the approval of the project structural engineer of record.

(b) Prior to the erection of a column, the controlling contractor must provide written notification to the steel erector if there has been any repair, replacement or modification of the anchor rods (anchor bolts) of that column.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-707, filed 06/19/02, effective 09/01/02].

WAC 296-155-708 Beams and columns.

(1) **General.**

(a) During the final placing of solid web structural members, the load must not be released from the hoisting line until the members are secured with at least two bolts per connection. These bolts must be of the same size and strength as shown in the erection drawings, drawn up wrench-tight or the equivalent as specified by the project structural engineer of record.

Exception: *See subsection (2) of this section.*

(b) A competent person must determine if more than two bolts are necessary to ensure the stability of cantilevered members; if additional bolts are needed, they must be installed.

(2) **Diagonal bracing.** Solid web structural members used as diagonal bracing must be secured by at least one bolt per connection drawn up wrench-tight or the equivalent as specified by the project structural engineer of record.

(3) (a) **Double connections at columns and/or at beam webs over a column.**
When two structural members on opposite sides of a column web, or a beam web over a column, are connected sharing common connection holes, at least one bolt with its wrench-tight nut must remain connected to the first member unless a shop-attached or field-attached seat or equivalent connection device is supplied with the member to secure the first member and prevent the column from being displaced (see Appendix E to this part for examples of equivalent connection devices).

(b) If a seat or equivalent device is used, the seat (or device) must be designed to support the load during the double connection process. It must be adequately bolted or welded to both a supporting member and the first member before the nuts on the shared bolts are removed to make the double connection.

(4) **Column splices.** Each column splice must be designed to resist a minimum eccentric gravity load of three hundred pounds (136.2 kg) located eighteen inches (.46 m) from the extreme outer face of the column in each direction at the top of the column shaft.

(5) **Perimeter columns.** Perimeter columns must not be erected unless:

(a) The perimeter columns extend a minimum of forty-eight inches (1.2 m) above the finished floor to permit installation of perimeter safety cables prior to erection of the next tier, except where constructibility does not allow (see Appendix D to this part);

(b) The perimeter columns have holes or other devices in or attached to perimeter columns at forty-two to forty-five inches (107-114 cm) above the finished floor and the midpoint between the finished floor and the top cable to permit installation of perimeter safety cables required by WAC 296-155-716 (1)(b), except where constructibility does not allow. (See Appendix D to this part.)

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-708, filed 06/19/02, effective 09/01/02].

WAC 296-155-709 Open web steel joists.

(1) **General.**

(a) Where steel joists are used and columns are not framed in at least two directions with solid web structural steel members, a steel joist must be field-bolted at the column to provide lateral stability to the column during erection.

WAC 296-155-709 (Cont.)

Exception: *See (b) of this subsection. For the installation of this joist:*

(i) A vertical stabilizer plate must be provided on each column for steel joists. The plate must be a minimum of six inch by six inch (152 mm by 152 mm) and must extend at least three inches (76 mm) below the bottom chord of the joist with a 13/16-inch (21 mm) hole to provide an attachment point for guying or plumbing cables.

(ii) The bottom chords of steel joists at columns must be stabilized to prevent rotation during erection.

(iii) Hoisting cables must not be released until the seat at each end of the steel joist is field-bolted, and each end of the bottom chord is restrained by the column stabilizer plate.

(b) Where constructibility does not allow a steel joist to be installed at the column:

(i) An alternate means of stabilizing joists must be installed on both sides near the column and must:

- Provide stability equivalent to (a) of this subsection;
- Be designed by a qualified person;
- Be shop installed; and
- Be included in the erection drawings.

(ii) Hoisting cables must not be released until the seat at each end of the steel joist is field-bolted and the joist is stabilized.

(c) Where steel joists at or near columns span sixty feet (18.3 m) or less, the joist must be designed with sufficient strength to allow one employee to release the hoisting cable without the need for erection bridging.

(d) Where steel joists at or near columns span more than sixty feet (18.3 m), the joists must be set in tandem with all bridging installed unless an alternative method of erection, which provides equivalent stability to the steel joist, is designed by a qualified person and is included in the site-specific erection plan.

(e) A steel joist or steel joist girder must not be placed on any support structure unless such structure is stabilized.

(f) When steel joist(s) are landed on a structure, they must be secured to prevent unintentional displacement prior to installation.

(g) No modification that affects the strength of a steel joist or steel joist girder must be made without the approval of the project structural engineer of record.

(h) Field-bolted joists.

(i) Except for steel joists that have been preassembled into panels, connections of individual steel joists to steel structures in bays of forty feet (12.2 m) or more must be fabricated to allow for field bolting during erection.

(ii) These connections must be field-bolted unless constructibility does not allow.

WAC 296-155-709 (Cont.)

(i) Steel joists and steel joist girders must not be used as anchorage points for a fall arrest system unless written approval to do so is obtained from a qualified person.

(j) A bridging terminus point must be established before bridging is installed. (See Appendix E to this part.)

(2) **Attachment of steel joists and steel joist girders.**

(a) Each end of "K" series steel joists must be attached to the support structure with a minimum of two 1/8-inch (3 mm) fillet welds one inch (25 mm) long or with two 1/2-inch (13 mm) bolts, or the equivalent.

(b) Each end of "LH" and "DLH" series steel joists and steel joist girders must be attached to the support structure with a minimum of two 1/4-inch (6 mm) fillet welds two inches (51 mm) long, or with two 3/4-inch (19 mm) bolts, or the equivalent.

(c) Except as provided in (d) of this subsection, each steel joist must be attached to the support structure, at least at one end on both sides of the seat, immediately upon placement in the final erection position and before additional joists are placed.

(d) Panels that have been preassembled from steel joists with bridging must be attached to the structure at each corner before the hoisting cables are released.

(3) **Erection of steel joists.**

(a) Both sides of the seat of one end of each steel joist that requires bridging under Tables A and B must be attached to the support structure before hoisting cables are released.

(b) For joists over sixty feet, both ends of the joist must be attached as specified in subsections (2) and (4) of this section before the hoisting cables are released.

(c) On steel joists that do not require erection bridging under Tables A and B, only one employee must be allowed on the joist until all bridging is installed and anchored.

Table A-Erection of Bridging for Short Span Joists

Joist	Span		Joist	Span		Joist	Span
8L1	NM		22K10	40-0		14KCS1	NM
10K1	NM		22K11	40-0		14KCS2	NM
12K1	23-0		24K4	36-0		14KCS3	NM
12K3	NM		24K5	38-0		16KCS2	NM
12K5	NM		24K6	39-0		16KCS3	NM
14K1	27-0		24K7	43-0		16KCS4	NM
14K3	NM		24K8	43-0		16KCS5	NM

WAC 296-155-709 (Cont.)

14K4	NM		24K9	44-0		18KCS2	35-0
14K6	NM		24K10	NM		18KCS3	NM
16K2	29-0		24K12	NM		18KCS4	NM
16K3	30-0		26K5	38-0		18KCS5	NM
16K4	32-0		26K6	39-0		20KCS2	36-0
16K5	32-0		26K7	43-0		20KCS3	39-0
16K6	NM		26K8	44-0		20KCS4	NM
16K7	NM		26K9	45-0		20KCS5	NM
16K9	NM		26K10	49-0		22KCS2	36-0
18K3	31-0		26K12	NM		22KCS3	40-0
18K4	32-0		28K6	40-0		22KCS4	NM
18K5	33-0		28K7	43-0		22KCS5	NM
18K6	35-0		28K8	44-0		24KCS2	39-0
18K7	NM		28K9	45-0		24KCS3	44-0
18K9	NM		28K10	49-0		24KCS4	NM
18K10	NM		28K12	53-0		24KCS5	NM
20K3	32-0		30K7	44-0		26KCS2	39-0
20K4	34-0		30K8	45-0		26KCS3	44-0
20K5	34-0		30K9	45-0		26KCS4	NM
20K6	36-0		30K10	50-0		26KCS5	NM
20K7	39-0		30K11	52-0		28KCS2	40-0
20K9	39-0		30K12	54-0		28KCS3	45-0
20K10	NM		10KCS1	NM		28KCS4	53-0
22K4	34-0		10KCS2	NM		28KCS5	53-0
22K5	35-0		10KCS3	NM		30KCS3	45-0
22K6	36-0		12KCS1	NM		30KCS4	54-0
22K7	40-0		12KCS2	NM		30KCS5	54-0
22K9	40-0		12KCS3	NM			

NM = Diagonal bolted bridging not mandatory for joists under 40 feet.

WAC 296-155-709 (Cont.)

Table B-Erection Bridging for Long Span Joists				
Joist	Span		Joist	Span
18LH02	33-0		28LH06	42-0
18LH03	NM		28LH07	NM
18LH04	NM		28LH08	NM
18LH05	NM		28LH09	NM
18LH06	NM		28LH10	NM
18LH07	NM		28LH11	NM
18LH08	NM		28LH12	NM
18LH09	NM		28LH13	NM
20LH02	33-0		32LH06	47-0 through 60-0
20LH03	38-0		32LH07	47-0 through 60-0
20LH04	NM		32LH08	55-0 through 60-0
20LH05	NM		32LH09	NM through 60-0
20LH06	NM		32LH10	NM through 60-0
20LH07	NM		32LH11	NM through 60-0
20LH08	NM		32LH12	NM through 60-0
20LH09	NM		32LH13	NM through 60-0
20LH10	NM		32LH14	NM through 60-0
24LH03	35-0		32LH15	NM through 60-0
24LH04	39-0		36LH07	47-0 through 60-0
24LH05	40-0		36LH08	47-0 through 60-0
24LH06	45-0		36LH09	57-0 through 60-0
24LH07	NM		36LH10	NM through 60-0
24LH08	NM		36LH11	NM through 60-0
24LH09	NM		36LH12	NM through 60-0
24LH10	NM		36LH13	NM through 60-0
24LH11	NM		36LH14	NM through 60-0
28LH05	42-0		36LH15	NM through 60-0

NM = Diagonal bolted bridging not mandatory for joists under 40 feet.

WAC 296-155-709 (Cont.)

(d) Employees must not be allowed on steel joists where the span of the steel joist is equal to or greater than the span shown in Tables A and B except in accordance with WAC 296-155-709(4).

(e) When permanent bridging terminus points cannot be used during erection, additional temporary bridging terminus points are required to provide stability. (See Appendix E of this part.)

(4) **Erection bridging.**

(a) Where the span of the steel joist is equal to or greater than the span shown in Tables A and B, the following must apply:

(i) A row of bolted diagonal erection bridging must be installed near the midspan of the steel joist;

(ii) Hoisting cables must not be released until this bolted diagonal erection bridging is installed and anchored; and

(iii) No more than one employee must be allowed on these spans until all other bridging is installed and anchored.

(b) Where the span of the steel joist is over sixty feet (18.3 m) through one hundred feet (30.5 m), the following must apply:

(i) All rows of bridging must be bolted diagonal bridging;

(ii) Two rows of bolted diagonal erection bridging must be installed near the third points of the steel joist;

(iii) Hoisting cables must not be released until this bolted diagonal erection bridging is installed and anchored; and

(iv) No more than two employees must be allowed on these spans until all other bridging is installed and anchored.

(c) Where the span of the steel joist is over one hundred feet (30.5 m) through one hundred forty-four feet (43.9 m), the following must apply:

(i) All rows of bridging must be bolted diagonal bridging;

(ii) Hoisting cables must not be released until all bridging is installed and anchored; and

(iii) No more than two employees must be allowed on these spans until all bridging is installed and anchored.

(d) For steel members spanning over one hundred forty-four feet (43.9 m), the erection methods used must be in accordance with WAC 296-155-708.

(e) Where any steel joist specified in subsections (3)(b), (4)(a), (b), and (c) of this section is a bottom chord bearing joist, a row of bolted diagonal bridging must be provided near the support(s). This bridging must be installed and anchored before the hoisting cable(s) is released.

WAC 296-155-709 (Cont.)

(f) When bolted diagonal erection bridging is required by this section, the following must apply:

(i) The bridging must be indicated on the erection drawing;

(ii) The erection drawing must be the exclusive indicator of the proper placement of this bridging;

(iii) Shop-installed bridging clips, or functional equivalents, must be used where the bridging bolts to the steel joists;

(iv) When two pieces of bridging are attached to the steel joist by a common bolt, the nut that secures the first piece of bridging must not be removed from the bolt for the attachment of the second; and

(v) Bridging attachments must not protrude above the top chord of the steel joist.

(5) **Landing and placing loads.**

(a) During the construction period, the employer placing a load on steel joists must ensure that the load is distributed so as not to exceed the carrying capacity of any steel joist.

(b) Except for (d) of this subsection, no construction loads are allowed on the steel joists until all bridging is installed and anchored and all joist-bearing ends are attached.

(c) The weight of a bundle of joist bridging must not exceed a total of one thousand pounds (454 kg). A bundle of joist bridging must be placed on a minimum of three steel joists that are secured at one end. The edge of the bridging bundle must be positioned within one foot (.30 m) of the secured end.

(d) No bundle of decking may be placed on steel joists until all bridging has been installed and anchored and all joist bearing ends attached, unless all of the following conditions are met:

(i) The employer has first determined from a qualified person and documented in a site-specific erection plan that the structure or portion of the structure is capable of supporting the load;

(ii) The bundle of decking is placed on a minimum of three steel joists;

(iii) The joists supporting the bundle of decking are attached at both ends;

(iv) At least one row of bridging is installed and anchored;

(v) The total weight of the bundle of decking does not exceed four thousand pounds (1816 kg); and

(vi) Placement of the bundle of decking must be in accordance with (e) of this subsection.

(e) The edge of the construction load must be placed within one foot (.30 m) of the bearing surface of the joist end.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-709, filed 06/19/02, effective 09/01/02].

WAC 296-155-711 Systems-engineered metal buildings.

(1) All of the requirements of this part apply to the erection of systems-engineered metal buildings except WAC 296-155-707 (column anchorage) and WAC 296-155-709 (open web steel joists).

(2) Each structural column must be anchored by a minimum of four anchor rods (anchor bolts).

(3) Rigid frames must have fifty percent of their bolts or the number of bolts specified by the manufacturer (whichever is greater) installed and tightened on both sides of the web adjacent to each flange before the hoisting equipment is released.

(4) Construction loads must not be placed on any structural steel framework unless such framework is safely bolted, welded or otherwise adequately secured.

(5) In girt and eave strut-to-frame connections, when girts or eave struts share common connection holes, at least one bolt with its wrench-tight nut must remain connected to the first member unless a manufacturer-supplied, field-attached seat or similar connection device is present to secure the first member so that the girt or eave strut is always secured against displacement.

(6) Both ends of all steel joists or cold-formed joists must be fully bolted and/or welded to the support structure before:

(a) Releasing the hoisting cables;

(b) Allowing an employee on the joists; or

(c) Allowing any construction loads on the joists.

(7) Purlins and girts must not be used as an anchorage point for a fall arrest system unless written approval is obtained from a qualified person.

(8) Purlins may only be used as a walking/working surface when installing safety systems, after all permanent bridging has been installed and fall protection is provided.

(9) Construction loads may be placed only within a zone that is within eight feet (2.5 m) of the center line of the primary support member.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-711, filed 06/19/02, effective 09/01/02].

WAC 296-155-714 Falling object protection.

(1) Securing loose items aloft. All materials, equipment, and tools, which are not in use while aloft, must be secured against accidental displacement.

(2) Protection from falling objects other than materials being hoisted. The controlling contractor must bar other construction processes below steel erection unless overhead protection for the employees below is provided.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-714, filed 06/19/02, effective 09/01/02].

WAC 296-155-716 Fall protection.

(1) **General requirements.**

(a) Fall protection will be in accordance with chapter 296-155 WAC, Parts C-1 and K.

WAC 296-155-716 (Cont.)

(b) During steel erection activities, fall protection must be as required by chapter 296-155 WAC, Parts C-1 and K. Additionally, on multistory structures, perimeter safety cables must be installed at the final interior and exterior perimeters of the floors as soon as metal decking has been installed. See Appendix D.

(2) **Connectors.** Each connector must: Have completed connector training in accordance with WAC 296-155-717.

(3) **Custody of fall protection.** Fall protection provided by the steel erector must remain in the area where steel erection activity has been completed, to be used by other trades, only if the controlling contractor or its authorized representative:

(a) Has directed the steel erector to leave the fall protection in place; and

(b) Has inspected and accepted control and responsibility of the fall protection prior to authorizing persons other than steel erectors to work in the area.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-716, filed 06/19/02, effective 09/01/02].

WAC 296-155-717 Training.

(1) **Training personnel.** Training required by this section must be provided by a qualified person(s).

(2) **Fall hazard training.** The employer must provide a training program for all employees exposed to fall hazards as required by chapter 296-155 WAC, Part C-1.

(3) **Special training programs.** In addition to the training required in subsection (2) of this section, the employer must provide special training to employees engaged in the following activities:

(a) Multiple lift rigging procedure. The employer must ensure that each employee who performs multiple lift rigging has been provided training in the following areas:

(i) The nature of the hazards associated with multiple lifts; and

(ii) The proper procedures and equipment to perform multiple lifts required by WAC 296-155-704(5).

(b) Connector procedures. The employer must ensure that each connector has been provided training in the following areas:

(i) The nature of the hazards associated with connecting (see Appendix D for nonmandatory training guidelines); and

(ii) The establishment, access, proper connecting techniques, double connections, and work practices, required by WAC 296-155-708(3) and Part C-1, chapter 296-155 WAC.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-717, filed 06/19/02, effective 09/01/02].

WAC 296-155-72401 Appendix A-Guidelines for establishing the components of a site-specific erection plan: Nonmandatory guidelines for complying with WAC 296-155-703(5).

(1) General. This appendix serves as a guideline to assist employers who elect to develop a site-specific erection plan in accordance with WAC 296-155-703(5) with alternate means and methods to provide employee protection in accordance with WAC 296-155-704 (3)(e) and 296-155-709 (5)(d).

(2) Development of a site-specific erection plan. Pre-construction conference(s) and site inspection(s) are held between the erector and the controlling contractor, and others such as the project engineer and fabricator before the start of steel erection. The purpose of such conference(s) is to develop and review the site-specific erection plan that will meet the requirements of this section.

(3) Components of a site-specific erection plan. In developing a site-specific erection plan, a steel erector considers the following elements:

(a) The sequence of erection activity, developed in coordination with the controlling contractor, that includes the following:

(i) Material deliveries;

(ii) Material staging and storage; and

(iii) Coordination with other trades and construction activities.

(b) A description of the crane and derrick selection and placement procedures, including the following:

(i) Site preparation;

(ii) Path for overhead loads; and

(iii) Critical lifts, including rigging supplies and equipment.

(c) A description of steel erection activities and procedures, including the following:

(i) Stability considerations requiring temporary bracing and guying;

(ii) Erection bridging terminus point;

(iii) Anchor rod (anchor bolt) notifications regarding repair, replacement and modifications;

(iv) Columns and beams (including joists and purlins);

(v) Connections;

(vi) Decking; and

(vii) Ornamental and miscellaneous iron.

(d) A description of the fall protection procedures that will be used to comply with Part C-1, chapter 296-155 WAC.

(e) A description of the procedures that will be used to comply with WAC 296-155-714.

WAC 296-155-72401 (Cont.)

(f) A description of the special procedures required for hazardous nonroutine tasks.

(g) A certification for each employee who has received training for performing steel erection operations as required by WAC 296-155-717.

(h) A list of the qualified and competent persons.

(i) A description of the procedures that will be utilized in the event of rescue or emergency response.

(4) Other plan information. The plan:

(a) Includes the identification of the site and project; and

(b) Is signed and dated by the qualified person(s) responsible for its preparation and modification.
[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-72401, filed 06/19/02, effective 09/01/02].

WAC 296-155-72402 Appendix B-Acceptable test methods for testing slip-resistance of walking/working surfaces. Nonmandatory guidelines for complying with WAC 296-155-706 (2)(c). The following references provide acceptable test methods for complying with the requirements of WAC 296-155-706 (2)(c). *Standard test method for using a portable inclineable articulated strut slip tester (PIAST)(ASTM F1677-96) *standard test method for using a variable incidence tribometer (VIT)(ASTM F1679-96).
[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-72402, filed 06/19/02, effective 09/01/02].

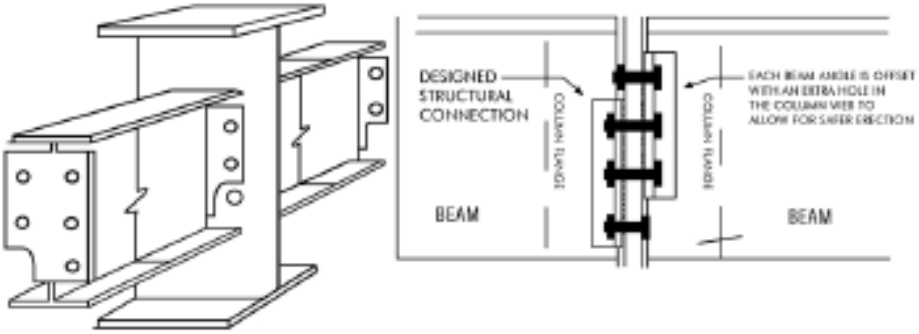
WAC 296-155-72403 Appendix C-Training: Nonmandatory guidelines for complying with WAC 296-155-717. The training requirements of WAC 296-155-717 will be deemed to have been met if employees have completed a training course on steel erection, including instruction in the provisions of this WAC that has been approved by the U.S. Department of Labor Apprenticeship Training Employer Labor Services or an approved state apprenticeship council. A training program may include the following:

- Multiple lift rigging procedures;
- Structural steel assembly;
- Open web steel joists;
- Panelized joist election;
- Preengineered metal buildings;
- Installation of steel decking; and
- Site conditions and construction sequence.

[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-72403, filed 06/19/02, effective 09/01/02].

WAC 296-155-72404 Appendix D-Perimeter columns: Nonmandatory guidelines for complying with WAC 296-155-708(5). To protect the unprotected side or edge of a walking/working surface in multistory structures, when holes in the column web are used for perimeter safety cables, the column splice must be placed sufficiently high so as not to interfere with any attachments to the column necessary for the column splice. Column splices are recommended to be placed at every other or fourth levels as design allows. Column splices at third levels are detrimental to the erection process and should be avoided if possible.
[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-72404, filed 06/19/02, effective 09/01/02].

WAC 296-155-72405 Appendix E-Double connections: Illustrations of a clipped end connection and a staggered connection: Nonmandatory guidelines for complying with WAC 296-155-708 (3)(a).



[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-72405, filed 06/19/02, effective 09/01/02].

WAC 296-155-72406 Appendix F-Typical installations for bridging: Nonmandatory guidelines for complying with chapter 296-155 WAC. Employers must comply with fall restraint and fall arrest as stated in Part C-1, chapter 296-155 WAC.

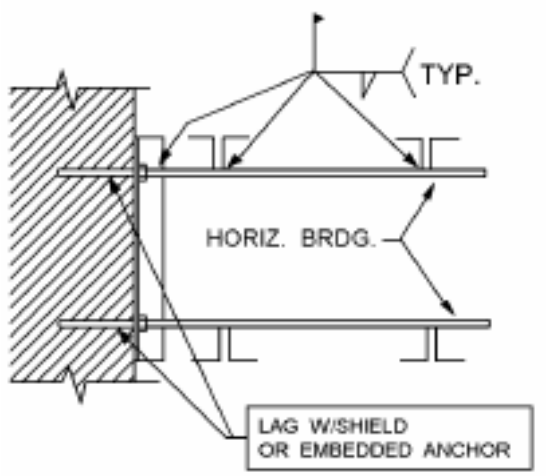


Illustration 1 – HORIZONTAL BRIDGING – TERMINUS AT WALL

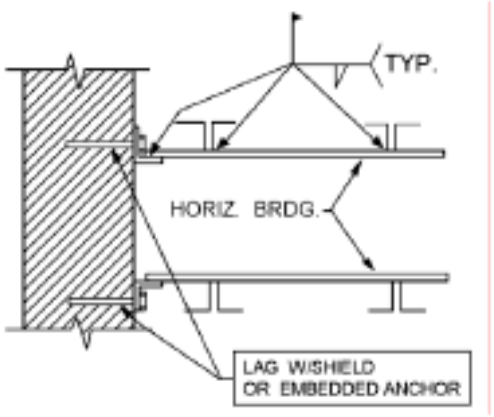


Illustration 2 – HORIZONTAL BRIDGING – TERMINUS AT WALL

WAC 296-155-72406 (Cont.)

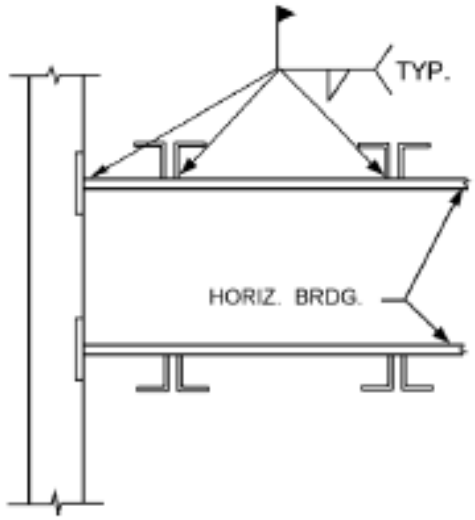


Illustration 3 – HORIZONTAL BRIDGING – TERMINUS AT PANEL WALL

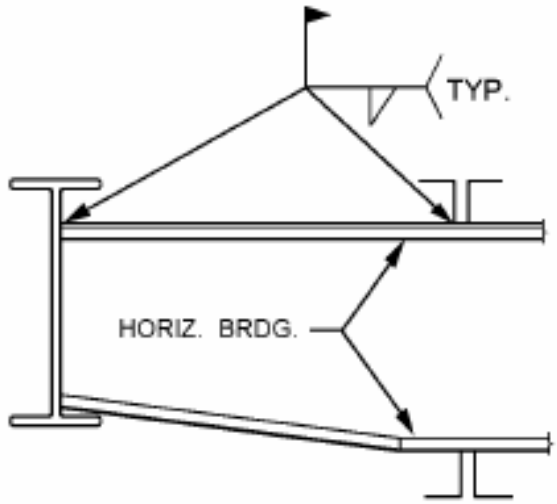


Illustration 4 – HORIZONTAL BRIDGING – TERMINUS AT STRUCTURAL SHAPE

WAC 296-155-72406 (Cont.)

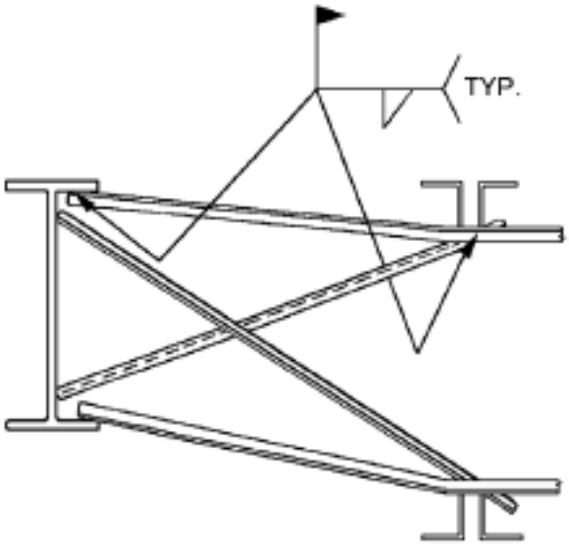


Illustration –5 HORIZONTAL BRIDGING – TERMINUS AT STRUCTURAL SHAPE WITH OPTIONAL "X-BRIDGING

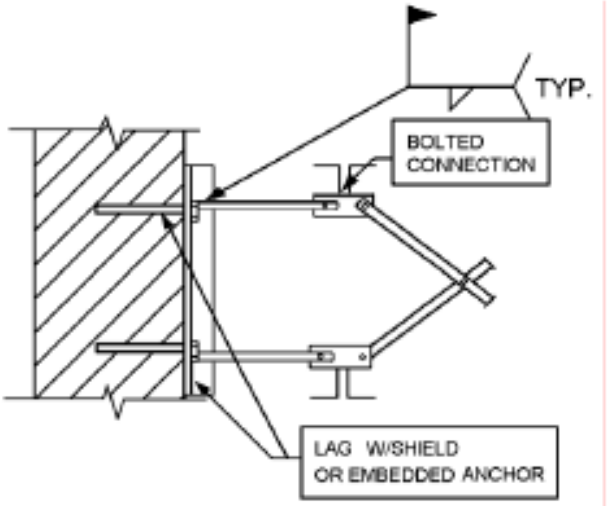


Illustration 6 – BOLTED DIAGIONAL BRIDGING – TERMINUS AT WALL

WAC 296-155-72406 (Cont.)

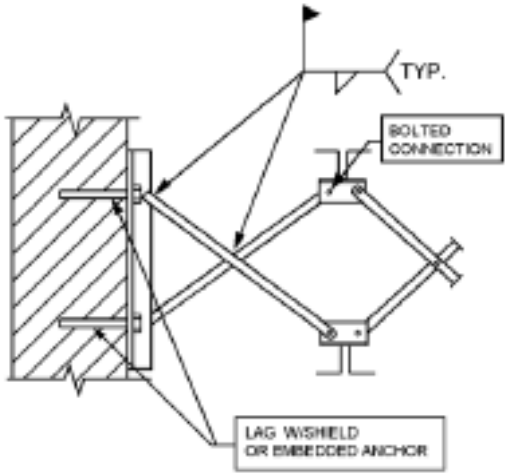


Illustration 7 – BOLTED DIAGIONAL BRIDGING – TERMINUS AT WALL

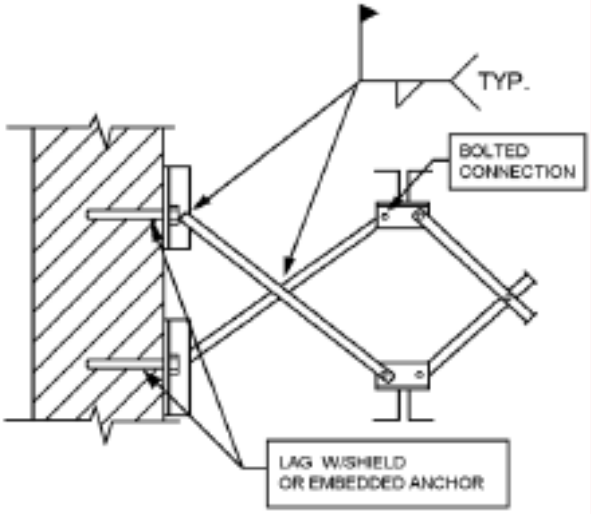


Illustration 8 – BOLTED DIAGIONAL BRIDGING – TERMINUS AT WALL

WAC 296-155-72406 (Cont.)

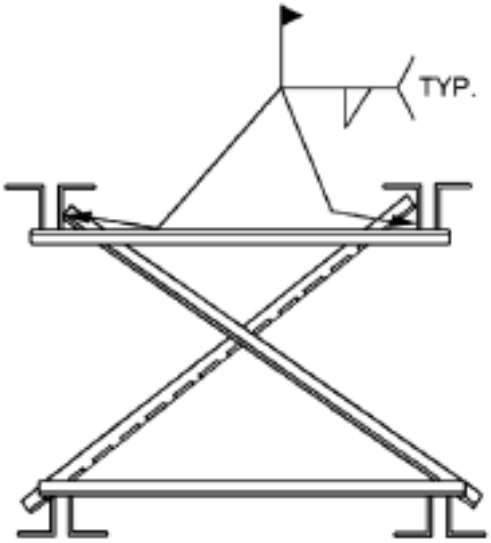


Illustration 9 – JOINT PAIR BRIDGING – TERMINUS POINT

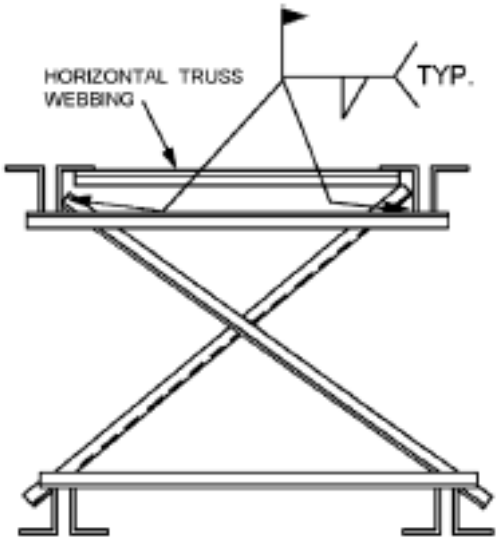


Illustration 10 – JOISTS PAIR BRIDGING – TERMINUS POINT WITH HORIZONTAL TRUSS

WAC 296-155-72406 (Cont.)

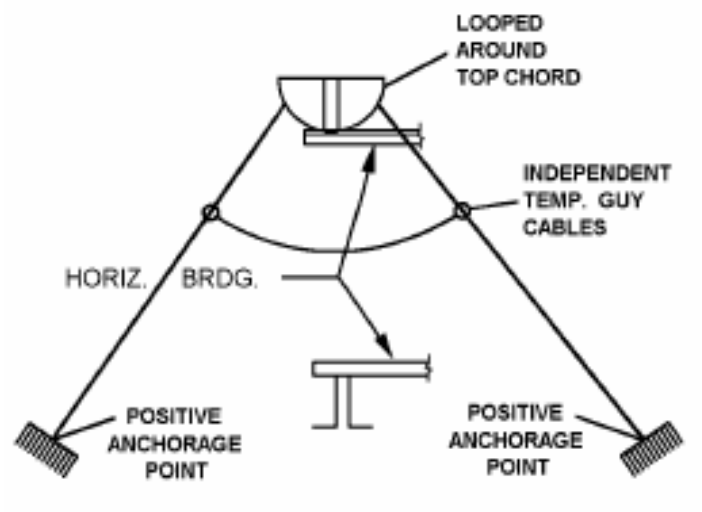


Illustration 11 – HORIZONTAL BRIDGING - TERMINUS POINT SECURED BY TEMP. GUY CABLES

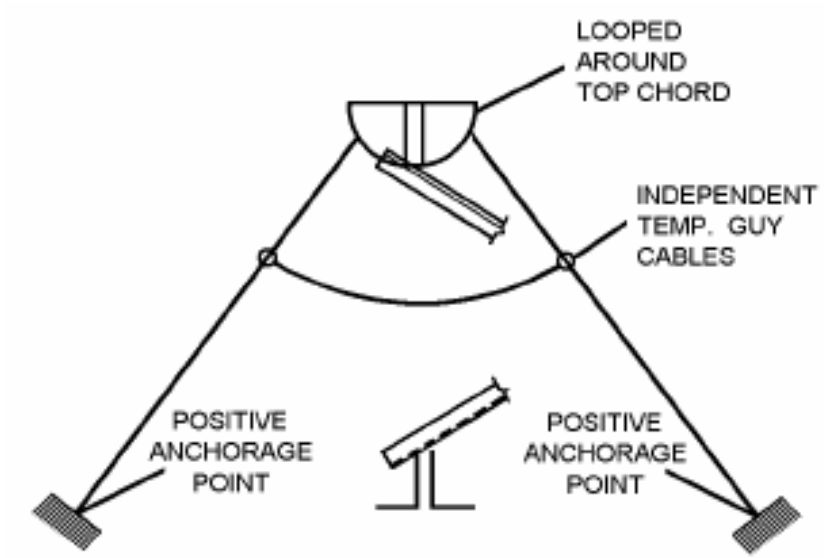


Illustration 12 – DIAGIONAL BRIDGING – TERMINUS POINT SECURED BY TEMP. GUY CABLES

WAC 296-155-72406 (Cont.)

Employers must comply with fall restraint and fall arrest as stated in Part C-1, chapter 296-155 WAC.
[Statutory Authority: RCW 49.17.010, .040, .050. 02-13-115 (Order 01-38), § 296-155-72406, filed 06/19/02, effective 09/01/02].

APPENDIX B
SITE SPECIFIC ERECTION PLAN AND CHECK LIST (EXAMPLE FORM)

Site Specific Steel Erection Plan and Checklist

Job Name:_____

Job Number: _____ Date:_____

Erector:_____ Project Eng._____

Sheeter:_____ Qualified Person:_____

Anchor Bolt Cont.:_____ Fabricator:_____

Crane Optr:_____ Qualified Rigger:_____

Scope of Work

Pre-Engineered Metal Building	☐	Sq. Ft._____	Tons_____
Conventional Steel Building	☐	Sq. Ft._____	Tons_____
Roofing	☐	Sq. Ft._____	Tons_____
Siding	☐	Sq. Ft._____	Tons_____
Decking	☐	Sq. Ft._____	Tons_____
Miscellaneous Steel	☐	Sq. Ft._____	Tons_____
General Miscellaneous	☐	Sq. Ft._____	Tons_____

General Description of Work:_____

Footings, Piers, Walls and Anchor Bolts

1. Has concrete reached 75% of sufficient strength? ☐ Yes ☐ No
2. Proof of Strength:
   a. ASTM test method results ☐ Yes ☐ No
   b. Engineer verification ☐ Yes ☐ No
3. Were anchor bolts repaired, replaced or modified? ☐ Yes ☐ No
4. Was erector notified in writing? ☐ Yes ☐ No

Notification of Commencement of Steel Erection

1. Was written notification given to the erector? ☐ Yes ☐ No

Site Layout

1. Has controlling contractor provided adequate access to site? ☐ Yes ☐ No
2. Is laydown area firm, properly graded, well drained and accessible? ☐ Yes ☐ No

P:\XYZ Contractor\Forms\Site Specific Steel Erection Plan and Checklist

Pre-Construction Site Conference

Has a Pre-Construction Site Conference been held? ☐ Yes ☐ No

Please list those attending

_____ _____
_____ _____
_____ _____
_____ _____
_____ _____
_____ _____
_____ _____
_____ _____

Sequence of Erection Activity

1. Give a general sequence of erection activities: _____
_____
_____
_____

2. Material delivery date:_____

3. How will activities be coordinated with other trades?_____
_____
_____

Cranes

1. Crane Type:_____
2. Crane Brand:_____
3. Crane Capacity:_____
4. How is the site prepared for the crane?_____
_____
5. How many different locations will the crane have and where are they?_____
_____
_____
6. What is the path for overhead loads?_____
_____
7. How will employees be notified of overhead loads?_____
_____
_____
8. Are there any critical lifts? (75% of capacity or dual crane) ☐ Yes ☐ No
   a. How many? _____
9. Describe critical lifts:_____
_____
_____
10. Are lift permits attached for critical lifts? ☐ Yes ☐ No
11. Are lift permits attached for all lifts over 5,000 lbs.? ☐ Yes ☐ No

Steel Erection Activities / Procedures (give a description of the following items and how they will be performed)

1. Temporary Bracing / Guying _____
   _____
   _____

2. Repair, Replacement or Modification of Anchor Bolts:_____
   _____
   _____

3. Columns / Beams (Joists or Purlins): _____
   _____
   _____

4. Connections:_____
   _____

5. Decking:_____
   _____
   _____

6. Roofing:_____
   _____
   _____

7. Siding:_____
   _____
   _____

8. Steel Grating:_____
   _____
   _____

9. Handrail or Miscellaneous Iron:_____
   _____
   _____

Fall Protection (Please identify the Fall Protection procedures for the following tasks):

1. Erection of vertical structural members
   - ☐ JLG Lift / Tie-Off
   - ☐ Scissor Lift / Guardrails
   - ☐ Vertical Lifeline / Harness and Lanyard
   - ☐ Retractable Lanyard / Harness
   - ☐ Other – Explain _____

2. Erection Horizontal Structural Members
   - ☐ JLG Lift / Tie-Off
   - ☐ Scissor Lift / Guardrails
   - ☐ Vertical Lifeline / Harness and Lanyard
   - ☐ Retractable Lanyard / Harness
   - ☐ Other – Explain _____

3. Installation of Siding & Associated Insulation
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

4. Installation of Roofing & Associated Insulation
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

5. Installation of Decking
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

6. Unprotected Sides / Edges
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

7. Leading Edges
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

8. Holes
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

9. Wall Opening
- ☐ JLG Lift / Tie-Off
- ☐ Scissor Lift / Guardrails
- ☐ Vertical Lifeline / Harness and Lanyard
- ☐ Retractable Lanyard / Harness
- ☐ Other – Explain _____

10. Has fall protection training been documented? ☐ Yes ☐ No
11. Is a competent person on-site at all times? ☐ Yes ☐ No
12. Were fall protection systems designed by a Qualified Person? ☐ Yes ☐ No

Falling Object Protection

1. Method for securing loose items aloft:_____
_____
_____

2. Are all personnel wearing hardhats? ☐ Yes ☐ No
3. Are erection areas properly barricaded? ☐ Yes ☐ No

Hazardous Non-Routine Tasks

1. Are Job Safety Analyses performed on all non-routine hazardous tasks? ☐ Yes ☐ No
2. Attach JSA's.

Training Certification

1. Are all personnel properly trained for performing steel erection activities? ☐ Yes ☐ No
2. Are all personnel properly trained for the use of fall protection systems? ☐ Yes ☐ No
3. Attach documentation of training.

List of Qualified and Competent Persons

1. Qualified Person for site specific erection plan:_____
2. Qualified Person for fall protection system design:_____
3. Qualified Rigger:_____
4. Crane Operator:_____
5. Crane Inspector:_____
6. Fall Protection Competent Person:_____

Emergency Rescue Procedures

☐ Self-Rescue	☐ Emergency Response Team	☐ Manbasket
☐ Stair Tower	☐ 1st Aid Trained Personnel	☐ Hoists
☐ Aerial Lifts	☐ Other	

Comments: _____

_____

_____

_____

_____

_____

Completed By:_____ Date:_____

Reviewed By:_____ Date:_____

APPENDIX C
STEEL STRUCTURE DESIGN TABLES (AISC) (HARWARD 1989)

Description	Abbreviate on drawings
Overall length	O'ALL
Unless otherwise stated	UOS
Diameter	DIA or Φ
Long	LG
Radius	r or RAD
Vertical	VERT
Mark	MK
Dimension	DIM
Near side, far side	N SIDE F SIDE
Opposite hand	OPP HAND
Centre to centre	C/C
Centre-line	℄
Horizontal	HORIZ
Drawing	DRG
Not to scale	NTS
Typical	TYP
Nominal	NOM
Reinforced concrete	RC
Floor level	FL
Setting out point	SOP
Required	REQD
Section A–A	A–A 1000 50
Right Angle	90°
45 degrees	45°
Slope 1:20	
20 number required	20 No
203 × 203 × 52 kg/m universal column	203 × 203 × 52 UC
406 × 152 × 60 kg/m universal beam	406 × 152 × 60 UB
150 × 150 × 10 mm angle	150 × 150 × 10 RSA (or L)
305 × 102 channel	305 × 102 ⊏ or 305 × 102 CHANN
127 × 114 × 29.76 kg/m joist	127 × 114 × 29.76 JOIST
152 × 152 × 36 kg/m structural tee	152 × 152 × 36 TEE

Description	Abbreviate on drawings
Girder	GDR
Column	COL
Beam	BEAM
High strength friction grip bolts	HSFG BOLTS
24 mm diameter bolts grade 8.8	M24 (8.8) BOLTS
Countersunk	CSK
Full penetration butt weld	FPBW
British Standard BS 4360: 1986	BS 4360: 86
100 mm length × 19 diameter shear studs	100 × 19 SHEAR STUDS
Plate	PLT
Bearing plate	BRG PLT
Packing plate	PACK
Gusset plate	GUSSET
30 mm diameter holding down bolts grade 8.8, 600 mm long	M30 (8.8) HD BOLTS 600 LG
Flange plate	FLG
Web plate	WEB
Intermediate stiffener	STIFF
Bearing stiffener	BRG STIFF
Fillet weld	FW (but use welding symbols!)
Machined surface	m/c
Fitted to bear	FIT
Cleat	CLEAT
35 pitches at 300 centres = 10500	35 × 300 c/c = 10500
70 mm wide × 12 mm thick plate	70 × 12 PLT
120 mm wide × 10 mm thick × 300 mm long plate	120 × 10 PLT × 300
25 mm thick	25 THK
80 mm × 80 mm plate × 6 mm thick	80 SQ × 6 PLT

LIST OF REFERENCES

Adeli, H. (1988). *Interactive Microcomputer-Aided Structural Steel Design*., Prentice Hall, Inc., Englewood Cliffs, New Jersey.

AGC (2006). “The AGC's BIM Initiatives and the Contractor's Guide to BIM.” The Associated General Contractors of America. <http://www.aecbytes.com/buildingthefuture/2006/AGC_BIM.html> (Feb. 21, 2009).

AISC (2009). “Utilizing CIS/2 Interoperability.” American Institute of Steel Construction, <http://www.aisc.org/content.aspx?id=17574&terms=Electronic+Data+Interchange*> (Feb. 21, 2009).

AISC (2005) “Jobsite Layout, Mobilization, Equipment and Coordination.” American Institute of Steel Construction, Inc. Chicago, IL.

AISC (1999). *Construction Management of Steel Construction 1999.* American Institute of Steel Construction

AIA (1997). *AIA-B141 Standard Form of Agreement From between Owner and Architect of Architect’s Services, 1997*. American Institute of Architects.

AIA (2002). *The Architect's Handbook of Professional Practice.* John Wiley and Sons, Inc., New York, NY.

AIM (2009). “Automatic Identification and Mobility (AIM) technologies.” Association for Automatic Identification and Mobility. <http://www.aimglobal.org/> (Feb. 21, 2009).

Ames, A. L., Nadeau, D. R., and Moreland, J. L. (1996). *VRML 2.0 Sourcebook*. 2nd ed., John Wiley & Sons, Inc., New York, NY.

Bazjanac, V. (2005). “Model based cost and energy performance estimation during schematic design.” *CIB w78 - 22nd International Conference on Information Technology in Construction*. International Council for Research and Innovation in Building and Construction, Dresden, Germany, CIB.

Chau, K. W., Anson, M., and Zhang, J. P. (2003). “Implementation of visualization as planning and scheduling tool in construction.” *Building and Environment*, 38(5), 713-719.

Chin, S., Yoon, S., Choi, C., and Cho, C. (2008). "RFID+4D CAD for Progress Management of Structural Steel Works in High-Rise Buildings." *Journal of Computing in Civil Engineering*. 22(2), 74-89.

Clemen, R., and Reilly, T. (2001). *Making Hard Decisions*, Duxbury, Pacific Grove, CA.

CIS/2 (2003). “CIMsteel Integration Standards Release 2: Second Edition (2003).” CIMsteel, <http://www.cis2.org/> (Feb. 21, 2009).

Cormen, T. H., Leiserson, C. E., Rivest, R. L. and. Stein, C., (2001). "Single-Source Shortest Paths". *Introduction to Algorithms* (2nd). Cambridge, Massachusetts: MIT Press. pp. 580–619.

Crowley, A. J. and Watson, A. S. (2000). "CIMsteel Integration Standards Release 2." The Steel Construction Institute, < http://www.cis2.org/> (Feb. 21, 2009).

Dawood, N., Sriprasert, E., Mallasi, Z., and Hobbs, B. (2002). "Development of an integrated information resource base for 4D/VR construction process simulation." *Automation in Construction*, 12, 123–131.

Dessler, G (2001). *Management: Leading People and Organizations in the 21st Century*. Prentice-Hall, Inc., Upper Saddle River, New Jersey 07458.

Dressen, D.(2008). "Large Memory RFID System Solution." www.atmel.com, <http://www.atmel.com/dyn/resources/prod_documents/secrerf_largemem_3_04.pdf > (March. 12, 2009).

Eastman, C. M. (1999). *Building Product Models: Computer Environments Supporting Design and Construction*. 1st ed., CRC Press, Inc. Boca Raton, FL, USA.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, Wiley & Sons, Inc., Hoboken, NJ.

EPM (2006). "Express Data Manager (EDM)." Jotne EPM Technology AS, <http://www.epmtech.jotne.com/products.41332.en.html > (Feb. 21, 2009).

Engel, I. (1988). *Structural Steel in Architecture and Building Technology*. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Ergen, E., Akinci, B. (2006). "Locating Building Components within a Facility Using Radio Frequency Identification Technology." 11th International Conference on Computing in Civil and Building Engineering, June 14-16, Montreal, Canada.

Express (2005). "Express Engine Project Release 3.2." Craig Lanning, <http://exp-engine.sourceforge.net/> (Feb. 21, 2009).

Gokce, K., Scherer, R. and Dikbas, H. (2007). "IFC Based Computer-Integrated Construction Project Management Model." *CIB w78 - 23nd Inter-national Conference on Information Technology in Construction*. International Council for Research and Innovation in Building and Construction, Dresden, Maribor, Slovenia, CIB.

Groebner, D., Shannon, P., Fry, P. and Smith K. (2008). *Business Statistics: A Decision-Making Approach*. Prentice-Hall, Inc., Upper Saddle River, New Jersey 07458.

Hardin, B. (2009). *BIM and Construction Management*, Wiley Publishing, Inc., Indianapolis, Indiana.

Hayward, I., and Weare, F. (1989). *Steel Detailers' Manual*, BSP Professional Books, Blackwell Scientific Publications Ltd., Osney Mead, Oxford.

Howard R., and Bjork, B. (2007). "Building Information Models-Experts' Views on BIM/IFC Developments." *CIB w78 - 23nd Inter-national Conference on Information Technology in Construction*. International Council for Research and Innovation in Building and Construction, Dresden, Maribor, Slovenia, CIB.

Hubbard, D. (2007). *How to Measure Anything: Finding the Value of Intangibles in Business*, John Wiley & Sons, London.

Hubbard, D. (2009). *The Failure of Risk Management: Why It's Broken and How to Fix It*, John Wiley & Sons, London.

Hu, W. (2008). "Integration of RFID and 4D CAD in Construction Management." Journal of Tsinghua Science and Technology. 13(S1), 151-157.

Issa, R. R.A., Flood, I., and O'Brien, W.J. (2003). *4D CAD and Visualization in Construction: Developments and Applications*. A.A. Balkema Publishers, Lisse.

Johnston, B. G., Lin, F. (1974). *Basic Steel Design.* Civil Engineering and Engineering Mechanics Series, Prentice-Hall, Inc., Englewood Cliffs, N.J.

Kenley, R,, and Seppanen, o. (2009). *Location-based Management for Construction*, Spon Press, New York, NY.

Koo, B. and Fischer, M. (2000). "Feasibility of 4D CAD in commercial construction." *Journal of Construction Engineering and Management*, 126(4), 251–260.

Karttam, N. A., and Levitt, R. E. (1990). "Intelligent planning of construction projects." *Proc., Journal of Computing in Civil Engineering*. 4(2), 6.

Lipman R. R. and Reed K. A. (2006). "Visualization of Structural Steel Product Models." *ITcon*, 8, 51-64.

Lipman R. R. and Reed K. A. (2000). "Using VRML in Construction Industry Applications." *Web3D-VRML 2000 Symposium*, Virtual Worlds, Monterey, CA, 21-24.

Leicht, R. M. and Messner, J. I. (2007). "Comparing traditional schematic design documentation to a schematic building information model." *CIB w78 - 23nd Inter-national Conference on Information Technology in Construction*. International Council for Research and Innovation in Building and Construction, Dresden, Maribor, Slovenia, CIB.

Miles, S.. B., Sarma, S. E., and Williams J. R. (2008). *RFID Technology and Applications*, Cambridge University Press, Cambridge, UK.

Mooney, J. D. (2004). "IFIP 18th Computer Congress Tutorials." *Developing Portable Software*, Kluwer Academic Publisher, Toulouse, France, 54-84.

NIST (2009). “Manufacturing System Integration.” National Institute of Standards and Technology. < http://www.nist.gov/mel/msid/index.cfm> (Feb. 21, 2009).

Newman, A. (1997). *Metal Building Systems*, McGraw-Hill, New York.

Nicholas Metropolis (1987), The beginning of the Monte Carlo method, *Los Alamos Science*, 1987 Special Issue dedicated to Stanislaw Ulam

Olbina, S. (2005). *Decision-making framework for the selection and Design of Shading Devices* PhD Dissertation, the Virginia Polytechnic Institute and State University, Blacksburg, VA.

OSHA (2007). *Occupational Safety and Health Simplified for the Construction Industry,* Government Institutes, an imprint of The Scarecrow Press, Inc., Lanham, Maryland.

Pazlar, T. and Turk, Z. (2007). “Evaluation of IFC Optimization.” *CIB w78 - 23nd Inter-national Conference on Information Technology in Construction*. International Council for Research and Innovation in Building and Construction, Dresden, Maribor, Slovenia, CIB.

Podbreznik, P. and Rebolj, D. (2007). “Real-Time Activity Tracking System-The development Process.” *CIB w78 - 23nd Inter-national Conference on Information Technology in Construction*. International Council for Research and Innovation in Building and Construction, Dresden, Maribor, Slovenia, CIB.

ProjectDox (2009). “Project Information Management.” Avolve Software Corporation ASC. <http://www.projectdox.com> (Feb. 21, 2009).

Rapp, W. G. (1980). *Construction of Structural Steel Building Frames (second edition).* Robert E. Krieger Publishing Company, Inc., Malabar, FL and John Wiley & Sons, Inc. New York

Russell, M (2007). “GPS and RFID Package Tracking.” EzineArticles.com. <http://ezinearticles.com/?GPS-and-RFID-Package-Tracking&id=513239> (Feb. 21, 2009).

Sacks, R., Eastman, C., Israel Kaner and Jeong, Y. (2008). “R&D of BIM Exchange Standards for IFCs: A Case Study of Architectural Precast Facades” *the 12th International conference on Computing in Civil and Building Engineering (ICCCBE-XII), jointly with the International Conference on Information Technology in Construction 2008 (INCITE 2008)*, Beijing, China,

Sawyer, T. (2008). "Modeling Supply Chains.” Journal of Engineering News-Record. 260(14), 24-27.

Shi, W., Tudoreanu, E. and Xie, H. (2006). “Development of Virtual Reality Safety-Training System for Construction Workers.” *6th International Conference on Construction 6th International Conference on Construction Applications of Virtual Reality,* Orlando, Florida, USA.

Sprague, R. and Carlson, E. (1982). *Building Effective Decision Support Systems*, Prentice-Hall, London.

STEP (2006). “ST-Developer.” STEP Tools, Inc. <http://www.steptools.com/> (Feb. 21, 2009).

Ville, B. (2006). *Decision Trees for Business Intelligence and Data Mining—Using SAS Enterprise Miner*, SAS Institute Inc., Cary, North Carolina 27513.

Waldner, J. (2008). *Nanocomputers and Swarm Intelligence*. John Wiley & Sons, London.

Welch, B. (2000). *Practical Programming in Tcl and Tk.* 3rd ed., Prentice Hall, Upper Saddle River, NJ.

Wilson, J. L., Lennox, J., and Bryan, P. Y. (1994). *3-D modeling as a tool to improve integrated design and construction*, Construction Industry Institute, the University of Texas at Austin, Austin, TX.

Wyzalek, J. (2001). *Enterprise Systems Integration*, CRC Press LLC, Boca Raton, FL.

Xie, H. (2005). *User model drive architecture for information retrieval in construction project management*, PhD Dissertation, the University of Florida, Gainesville, FL.

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