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USING RFID AND REAL-TIME VIRTUAL REALITY SIMULATION FOR OPTIMIZATION IN STEEL CONSTRUCTION

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SUMMARY: *This research discusses the implementation of Radio Frequency Identification (RFID) and Virtual Reality (VR) simulations in construction processes and projects. The purposes are to improve the control and monitor of construction projects and to find the optimized solutions for construction processes. The authors have implemented a Building Information Model (BIM) and used it in a VR world. The details of the BIM model are the basis for the optimization analysis in construction. Using VR technology in the analysis helps the architect, engineer, and contractor (A/E/C) team to understand construction projects and plans. The team can gain experience by developing and critiquing construction sequences in a full-scale virtual environment. The team can also gain interactive operation, simulation, and optimization experiences. VR simulations in construction should not only focus on the pre-construction stage, but also record the site changes and update the system in real time. The real-time VR simulation in this study can be used throughout the entire construction process. In particular, the technology will help in the optimization of steel installation sequencing during construction.*

The real-time VR simulation is done via the use of RFID and its related database. In this study, the authors are experimenting with the use of a data hub for staging and cleansing the data before feeding it into the BIM database. This BIM/RFID enriched VR environment improves the straight forward representations which VR simulation can provide, automates construction data collection by acquiring RFID in real time, and accomplishes data integration through the use of BIM. The A/E/C team can use the system to explore different construction sequences, temporarily re-arrange facility or equipment locations, coordinate trades, identify safety issues, and improve constructability.

KEYWORDS: *Radio Frequency Identification (RFID), Real-Time Simulation, Virtual Reality (VR), Optimization, Data Hub, Building Information Modeling (BIM).*

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1. INTRODUCTION

Advanced uses of Virtual Reality (VR) technology in construction have been implemented in various projects. These implementations have incorporated a multitude of hardware, software, and networks with the functions of storing, transferring, processing and presenting information. Currently, VR implementations in construction are focused mainly on the pre-construction stage or are performed before the start of some critical milestone events for the purpose of forecasting, simulation, and analysis. VR implementations face the challenge of combining software from different sources, to make the software adapt to different operations or to solve conflicts within the existing software environment.

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 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 for information treatment serve the purpose of finding the optimized solution to the practical problems of the real world. All these procedures require interdisciplinary research collaboration with the focus on analytical reasoning, which is facilitated by interactive visual interfaces, such as VR.

This research discusses the implementation of Radio Frequency Identification (RFID) and Virtual Reality (VR) simulations in construction processes and projects to improve the control and monitoring of construction projects and to find the optimized solutions for the construction processes. Using VR technology in the analysis helps the architect, engineer, and contractor (A/E/C) team understand construction projects and plans. The team can gain experience by developing and critiquing construction sequences in a full-scale virtual environment. The team can also gain interactive operation, simulation, and optimization experiences.

2. PROBLEM STATEMENT

The implementations of VR in construction include the development of walkthrough systems and models in design (such as space modeling, interior design, Heating Ventilation and Air Conditioning design, ergonomics and functional requirements) and in construction (such as site layout and evaluation of construction scenarios). The use of VR in planning and monitoring construction processes could be achieved by robots, webcams, monitors, etc. But those tools lack the capacity to catch the site changes and update the VR system in real time and in detail.

With the decreased cost and wide acceptance of RFID in manufacturing, delivering, storage, selling, and shipment, RFID tags can be found affixed to various merchandise. RFID tags on the construction materials help improve the identification and tracking of the components'. This research suggests using an RFID/BIM enriched VR environment to assist decision-making in construction project management. This research proposes to accomplish information visualization and user-computer interaction in steel structure projects by displaying a BIM model in a VR environment and using web-based RFID to obtain real-time component data from the actual steel fabrication and erection sequence. This study would also explain how the structural steel component identification system, such as RFID, would combine BIM and VR to reduce mistakes in steel fabrication and erection. Finally, the study will show that the BIM/RFID enriched VR model in steel fabrication and erection can assist the decision-making process and facilitate the selection of an optimized erection sequence in steel construction.

3. LITERATURE REVIEW

3.1 Visualization and VRML

VRML is an acronym for the Virtual Reality Modeling Language. Using VRML 3D 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.

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 in representing space on the normal computer screen instead of the 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 1996).

Virtual reality models have a very strong advantage in visualization. Because of this graphical advantage, VR models can help builders better understand the design intents of construction projects, hence reducing mistakes in the construction and maintenance processes. Traditional VR models created by using VRML are usually difficult to update in real-time, because of the poor compatibility between VRML and other software, it is also strenuous to integrate a VR model with decision-support software.

3.2 Building Information Modeling (BIM)

The American Institute of Architects (AIA) 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 (Leicht 2007). BIM can substantially reduce lead times and make the construction process more flexible and less wasteful. BIM can document the entire building life cycle including the processes of construction and facility operation. Quantities and shared properties of materials can easily be extracted from the BIM database. 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).

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 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 a reality.

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).

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, 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.

Virtual models of construction projects can be built up based on 3DS (3D Studio), 3D AutoCAD, or BIM models, etc. VR is a set of technologies, such as computer graphics/displays, human computer interfaces and simulation, merged together. A research project called UC-win/Road was developed by FORUM8 Co., Ltd. The system is a 3D real-time VR software program providing engine and interface for simulation creation. The UC-win/Road system enables the creation of large scale 3D spaces for projects. Practical data features include standard database, a Web/Road Database and a LandXML data exchange function. It is equipped with a VR creation/editing function for road alignments, cross sections and terrain processing to traffic setup, model setup/processing, etc. It assists engineering design, development and research whilst also supporting advanced simulation by sunshine simulation, traffic flow simulation, manual drive simulation, etc., in addition to drive simulation (Lorentzen et al. 2009).

A VRML-based BIM visualization system will also be used to provide remote visual feedback to an operator or supervisor. Elements of the world model – the construction plane and the target components – will be modeled in VRML and displayed. 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 in the VR world and see that a water valve is located in the suspect location. Pointing out the possible fault locations is the first step in solving the problem. After finding out the reason for the problem, the next step is to correct the error or improve the situation. That will require the model to provide the specific valve size, manufacturer, part number, and any other relevant information for decision-making or problem solving. A VRML-based BIM visualization system can help reduce mistakes in design, construction, and maintenance; it can also support decision-making to offer users several options. But the system needs to have a tool to help it collect and update project information in real-time.

As Smith and Tardif (2009) had pointed out, BIM will push the building industry business process to reform in both the industry-wide changes in business practice and changes in each individual organization to adapt to the new business model. Nevertheless, the implementation of the RFID system in the consumer products industry is an excellent model for interoperability and industry-wide cooperation in the building industry. Implementation of RFID tagging technology could do much to enhance the quality, completeness, and currency of building information models.

3.3 Steel Identification with RFID

Most bar code implementations need to have human involvement in holding a scanner and scanning the bar codes one by one. Most RFID tags contain chips and antennas which receive and transmit signals and relieve users from tedious scanning work. The RFID chip has an integrated circuit for storing and processing information, modulating and demodulating a radio-frequency (RF) signal, and other specialized functions. The chip and antenna are 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) 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) The advantages and disadvantages of RFID are listed in Table 1.

TABLE 1. Advantages and disadvantages of using RFID

	RFID Performance	
Description	Advantage	Disadvantage
Technology	Mature technology after more than twenty years of development	The Passive Wave Range has a limitation of about 20 feet.
Accuracy	Adequate for building jobsite work.	More accuracy means higher cost. The reader plus PDA cost thousands of dollars.
Standard	There are hundreds of products available for users to choose from.	No universal standard nor universal ports. It is difficult to use tags/readers from different sources.
Cost	Cost of tags decrease with technology improvement. The cheapest tag is around 20-60 cents and can be recycled.	Prices of readers and stations are high.
Implementation	Widely used in retail and automobile industries for supply chain.	Inconvenient for multi-transaction tasks when transferring data from different users because of conflicts between software or missing connection ports.

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 by steel fabricators.

One implementation of active RFID technology in the construction industry is to support the visibility of assets, such as trailers, excavators, forklifts, light towers and other construction equipment. It can pinpoint the locations of heavy equipment for monitoring and control. It can facilitate the emergency evacuation of hazardous sites, asset tracking, and access control. Active RFID can automate order fulfilment 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.

According to Smith and Tardif (2009), business automation can be accelerated by keeping business partners in continuous communication. That could increase the amount of information exchanged electronically and lead to finding out potential problems early. Some information about buildings is rarely systematically collected or conveyed. For example, for a product, the manufacturer's name and model number, a product description, or a serial number may be missing from the building documentation. It may be about the identity of the product installed in a building. An enterprising recipient might scan the information from a paper document, but the integrity of the data depends on the scanner, the optical character recognition (OCR) software, and the structure of the database. To deliver this type of information in electronic form with the product, such as RFID, is a better option for recipients of the information. RFID technology can bring the construction industry significantly closer to the goal of up-to-date life cycle building information models at a minimal cost. It provides a platform for equal accessibility to everyone and future innovation for enterprising players,

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

Using serial numbers steel parts can be distinguished using RFID tags. A hand-held scanner may be introduced into the proposed model. It will be configurable with different computer systems and scheduling software. 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 the related information for a component 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. Using RFID in a construction process will allow for the updating of project information in real-time. However, just using RFID by itself does not help in reducing mistakes in the process; nor would it help with decision-making.

This research suggests that RFID tags should be used after the first step of fabrication when the major structural steel members 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. Then each piece of information scanned will be translated into a code that represents the steel. The data will be imported to the information system and change the color of the installed steel member in 4D VR model system. This serial-code system is different from the bar-code system. The serial-code system is not just a tracking code; it is part of the proposed real-time BIM/RFID-VR 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 code system or by creating a new standard to reflect the workflow or the supply chain.

The workflow used in deploying RFID is shown in Fig. 1. A manufacturer puts a code on a piece of steel then sends it to a fabricator. The fabricator reads it at the 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 fabrication schedule for the component. Other involved workers can see the related details of the piece of steel in real-time. After the fabricator's job is done, the piece of steel will be sent to the 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 system. The 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 BIM/RFID enriched VR visualization model.

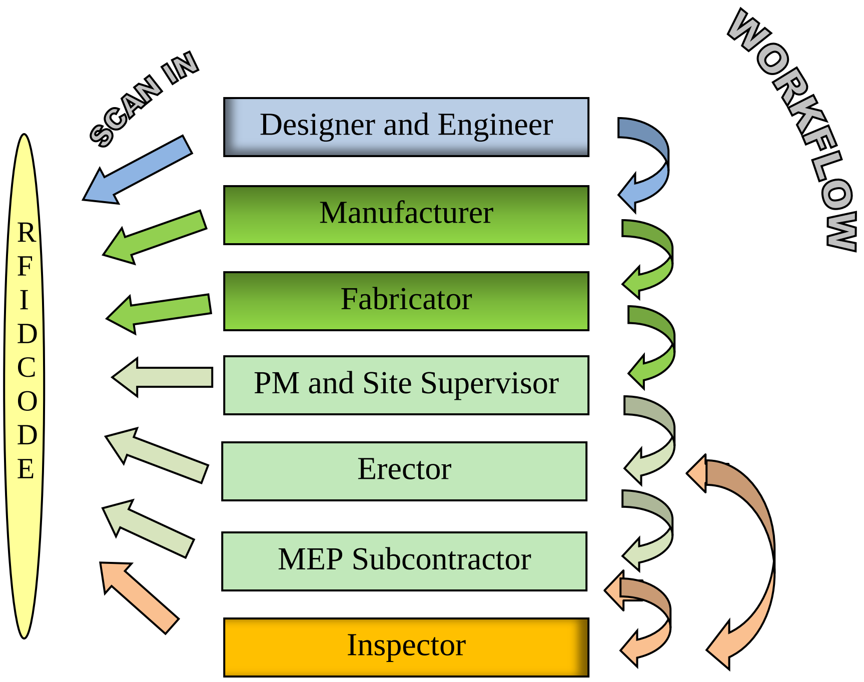

FIG. 1: RFID coding system workflow.

When an inspector visits a job site, he/she could first use this BIM/RFID VR virtualization model and by checking the BIM system will know what is going on at the site, to see if every sequence follows the inspection requirements. Then he/she could go to the jobsite to check the actual 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 reach a judgment on uncertain things, such as missing parts, delayed orders, and misused materials.

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 BIM/RFID VR model. The 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 transfer into drawing, inventory, and supply chain systems.

4. VIRTUAL REALITY (VR) SIMULATION IN STEEL CONSTRUCTION

The VR system is a simulation tool for visualizing construction projects, facilities, or elements. VR simulation in steel construction focuses on simulating the changed appearance of the steel structure with 3D type either on a computer screen or in immersive virtual environment. Virtual construction methodology is a technique that can solve problems during a virtual construction process before real construction starts.

In order to provide the virtual simulation of the geometric evolution of the steel construction on a project, the 3D VR model needs to be defined as a set of individual objects, each one representing a steel component. The VR steel model allows for the simulation of the steel construction process piece by piece. The 3D model of the steel construction can be created from BIM software. In the proposed BIM/RFID VR system, the authors used AutoDesk® Revit® to create a BIM steel structure model. Once the 3D BIM model was ready to be inserted into the VR world, the authors converted Revit® BIM model to VRML by transferring the model through Autodesk® VIZ®. The software needed is Autodesk® VIZ® (or 3DS Max), Revit® Architecture and a VRML viewer (e.g. BS Contact Stereo in the display lab).

In the BIM/RFID VR system, Industry Foundation Classes (IFC) is used to define the data model of the BIM system. IFC14 is a task and schema specification that provides standard ways to define information contained in BIM. IFC has the following features:

- An object-oriented data model developed by the International Alliance for Interoperability (IAI)
- Describe the relationships and properties of building specific objects.
- The IFC format is non-proprietary and is available globally to anyone defining AEC objects.
- The IFC format describes the behavior, relationship, and identity of a component object within a model.

5. IMPLEMENTATION OF RFID IN BIM MODELS FOR STEEL CONSTRUCTION

The construction jobsite has many uncertain conditions and risks. For example, site condition change (flooding or 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 for 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 the project safety record, or achieve better quality at the end of the construction process.

Fig. 2 shows the proposed BIM/RFID VR 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 in making decisions. Many software packages have it in their 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 support 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 integrate the supply chain system product data and sustainable manufacturing, 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 Fig. 2 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 identification techniques. 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.

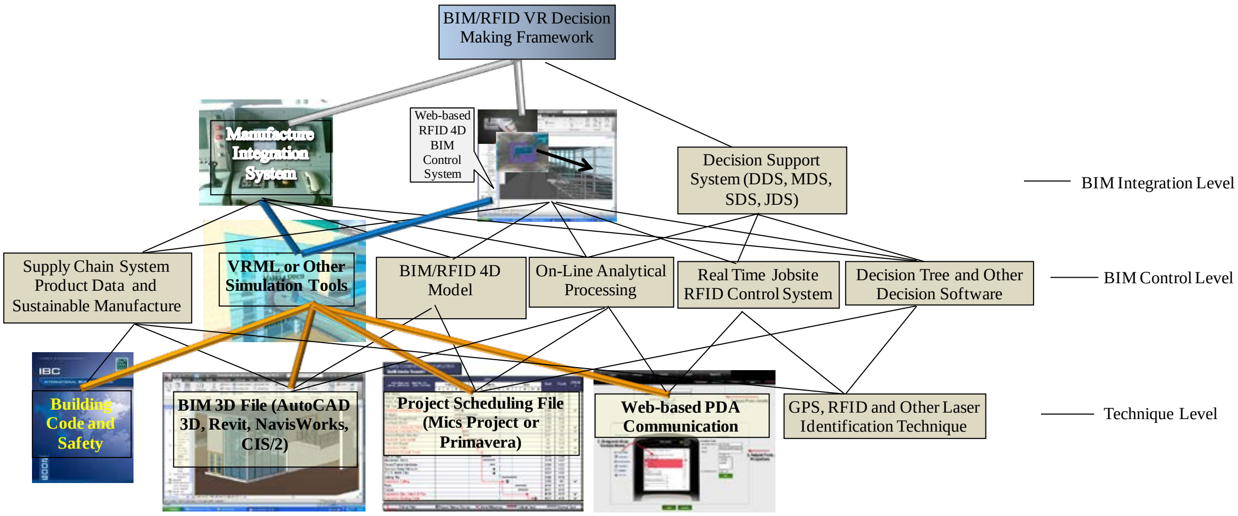

FIG. 2: BIM/RFID VR framework components and relationship.

6. USING RFID TO CONNECT THE VR WORLD WITH THE REAL CONSTRUCTION PROCESS

6.1 BIM database

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

6.2 BIM testing

After the needed data are collected from various databases, they will be sent to the testing part of the system, in which, VR simulation plays an important role. The testing center is a function block having intelligent and automatic transacting functions. It can use the 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. With the help of RFID, the BIM testing center can have project information updated in real time. The VR model is information rich and reflects the real job site situation.

6.3 BIM model base

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 for the BIM/RFID framework include: 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 it is eventually decided to change the design, the change will be made to the BIM project.

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

Fig. 3 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.

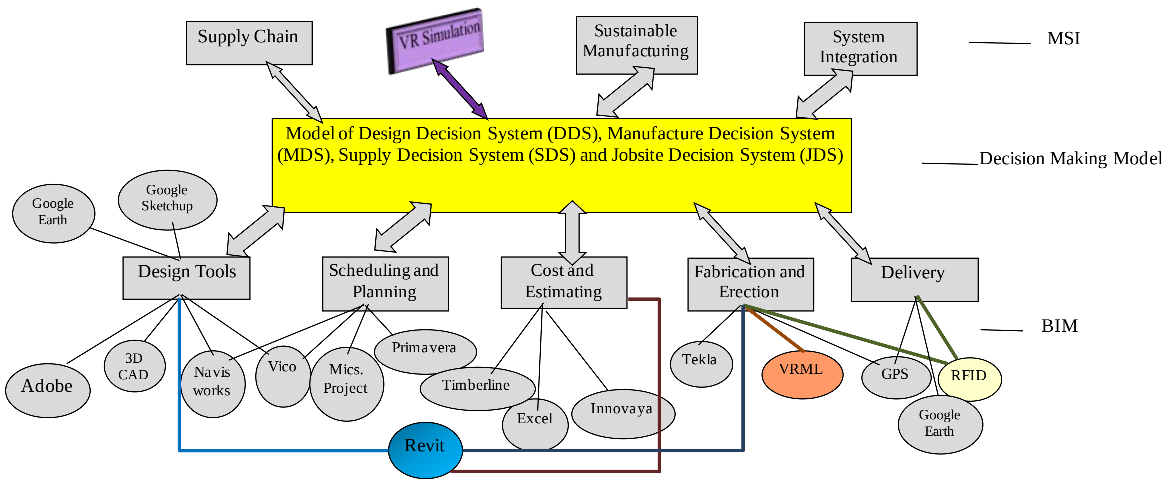

FIG. 3: BIM/RFID Framework network.

The RFID tags of steel components will be scanned when the delivery trucks enter the jobsite gate. Then the 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 then 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.

Fig. 4 (a)-(d) show how a column changes in a simulation of a multiple floor structural steel VR model. Fig. 4 (a) shows the column simulation in Sequence 1. The column RFID # C10A0301 in this 3D image has not been erected. The information on the RFID Tag of Column #C10A0301 includes: steel features, mill manufacture, inspector, storage, delivery and site location IDs and dates. If the memory is large enough, other information such as connection methods, welding methods, and so on may also be included.

Fig. 4 (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 a wireless PDA reader or manual typing. This task was also performed at Sequence 1.

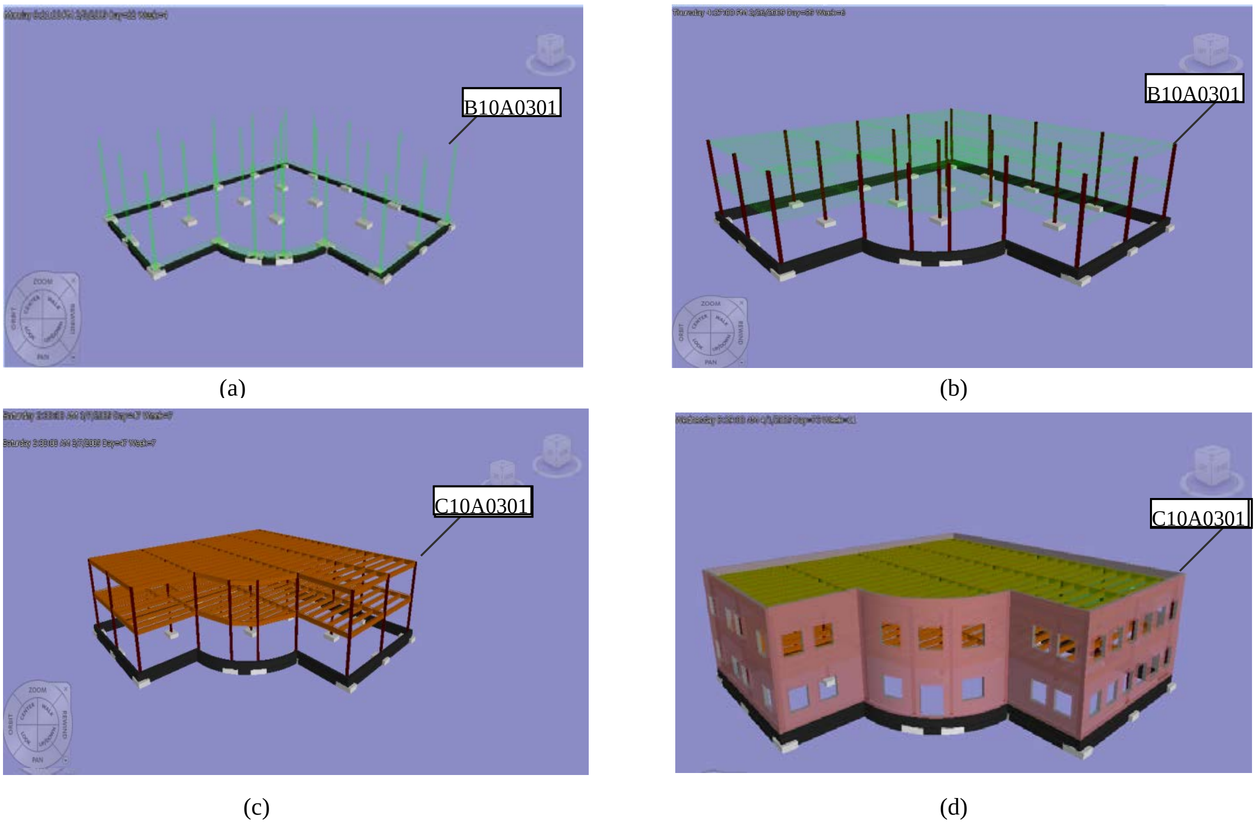

FIG. 4: VR BIM Model shows a column with RFID changes (The model is composed by using Revit 2008).

Fig. 4 (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 structural component's status. It should be inspected in detail by the foreman using an RFID reader to check the components RFID tags and connecting pieces.

Fig. 4 (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 member and its information may be found by checking its RFID tag and logging into the RFID database system in the BIM/RFID Framework. 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. These items still need RFID numbers to identify them. Their features and connecting information would be read from the RFID database system. The manufacturers of the small-piece members can attach RFID tags to the boxes or cartons of the small pieces as group IDs. Even components that are too small need to have RFID tag associated with them, because it is still necessary to assign them a RFID code so that every member can be represented in the model.

6.4 Case Study 1

In Case Study 1, a user is checking the details of the steel connection of a project. The user uses the RFID of the steel components to trace the members. 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, wrong side installation for #C10A3101, because a shear plate welded on #C10A3101 should face outside but is installed facing inside and the outside bolted connection is not strong enough to hold a canopy attachment. The user writes a RFI from their PDA system and scans the RFID tags of the connected beam and plate. The system uses its wireless connection to send the RFI to the site BIM/RFID Framework.

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

1) To reinstall the column.
2) To weld another shear plate on another side in the same place.
3) Redesign the bolted 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 the cost data for plate and bolts was found) 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 part order is sent to the supplier. This total change order used 20 minutes from the site problem to sending out a purchase order (P.O.).

Fig. 5 shows the different RFI flow between the traditional construction method and the RFID database method. In the traditional method, the RFI is sent to the Superintendent, PM, and AEC, then they go to find the answer and they issue a P.O. Usually the RFI take at least two days to process. The BIM/RFID decision-making model significantly shortens the process.

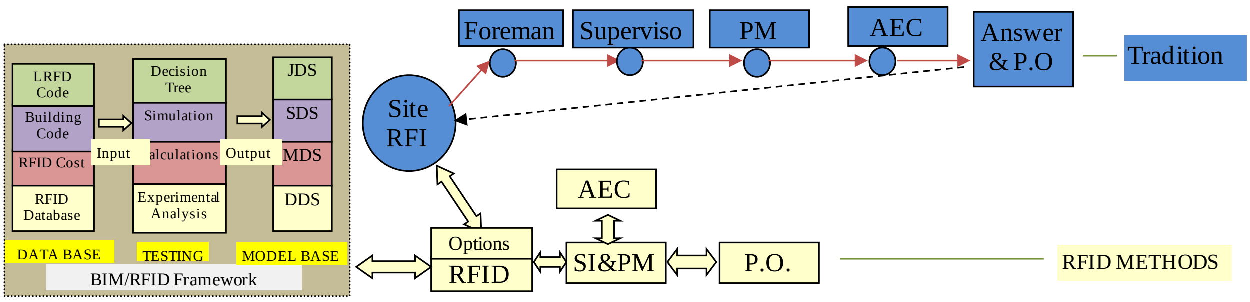

FIG. 5: Tradition RFI or RFC versus RFID jobsite flowchart.

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

7. THE CONCEPT OF DATA HUB

The data in the BIM/RFID VR framework's database comes from many resources. The information needs to be retrieved using a convenient filtering system so that users can have the information that they really want and not be bothered by a lot of irrelevant data.

The BIM/RFID Framework has to have data transaction and dialog integration functions compatible with the different software and functions integrated. A model typically may change 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).

All the heterogeneous data stored in the BIM/RFID VR framework's database have different formats. This research proposes to use the concept of a Data Hub to manage the data. Managing data in the Data Hub raises the concerns of acquiring, rationalizing, cleaning, transforming, and loading data into the Data Hub as well as the concerns of delivering the right data to the right consumer at the right time. (Berson and Dubov 2007)

Fig. 6 shows the architecture of the Data Hub data storage and support services in the context of the data management architecture of RFID data. The architecture includes data sources that feed the loading process, data access and data delivery interfaces, data Extract-Transform-Load (ETL) service layer, the Data Hub platform, and applications, such as real time jobsite control system and decision tree and other decision software which retrieve RFID data and operate on them.

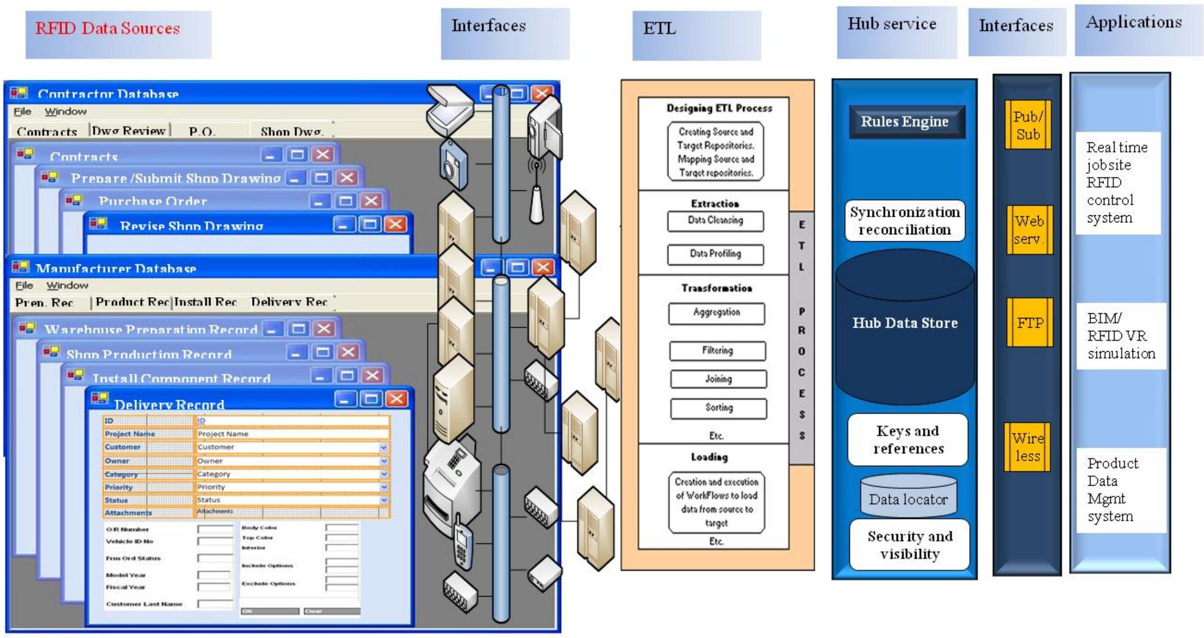

FIG. 6: Architecture of the Data Hub

The efficiency of managing RFID data depends on the good procedural understanding of data structures and operational concerns as data access interfaces. Because of the mobility and limited memory size of RFID chips, the other product-related information is stored in a server database. Those product-related data include enterprise reference data, such as the code tables used by an organization to provide product-name-to-product-code mapping, state code tables, branch numbers, account type reference tables, etc. When the data stored on RFID chips are loaded into the Data Hub automatically by scanners, the Data Hub service engine starts using information stored in the metadata repository to determine data attributes, formats, source system names, and location pointers. The benefits of using the Data Hub service engine include: (Berson and Dubov 2007)

- Synchronization and reconciliation of conflicting data changes.
- Enforcing semantic consistency of the information.
- Generating unique persistent identifiers by the Registry-style Data Hub, which allows the consuming application to either retrieve or assemble an integrated view.

The purpose of the Data Hub design is to build a complete transactional environment that maintains its data integrity. Implementing the Data Hub to manage RFID data can provide a sole source of changes that it propagates to all downstream systems that use this data. The data on RFID chips need accuracy in the matching and linking process. Data Hub environments implement data cleaning, standardization, and enrichment preprocessing in the Third-Party Data Provider and Acquisition/ETL zones before the data is loaded into the Data Hub.

8. CASE STUDY OF OPTIMIZATION BY PROPOSED SYSTEM FRAMEWORK

The name of the company in this case study is called Nice Quality Steel (NQS) Company. The company's existing software and equipment include: 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.

This BIM model can assist decision-making functions. All resolvable decision making questions are listed under a search menu. Users can navigate these questions in a catalog box. Users can fill out 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. The NQS Company work packages include fabrication and erection subcontractor work. They receive drawings and other design documents from Architects. If NQS Company already has 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 NQS Company 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 the components can be created as their design is completed. 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.

Fig. 7 shows the BIM flow for the NQS Company Construction in both fabrication and erection. It shows a view of the future job scope of the NQS Company. As a conclusion of the above analysis and BIM research for the NQS Company, BIM can definitely work for the NQS Company and bring more benefits to its workers and projects.

The NQS Company has an automatic control machine using a Computer Numerical Control (CNC) manufacturing system. The CNC manufacturing system has a Function Block which is the key for collecting and executing operating orders. The Function Block can activate the machine to orient the steel materials and cut or drill the material. When the architect and engineer use BIM tools to the 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 throughout the entire project. After the CNC machine makes the cut, an RFID tag is attached to the steel member to represent it. In this way, RFID works as the information carrier. So the BIM/RFID Framework (BRF) can link the CNC system using the RFID system.

From the first activity shown in Fig. 7, receiving the drawing, the BIM team creates 3D format Revit® and Navisworks® files. 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.

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.

8.1 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 of the NQS Company Company's projects are over a million dollars. This gives them more pressure for on-time delivery because these projects are usually located far away from their fabrication facility. Schedules are very condensed on those projects as well. The supply chain management (SCM) system is very important for the NQS Company and other parties on the project.

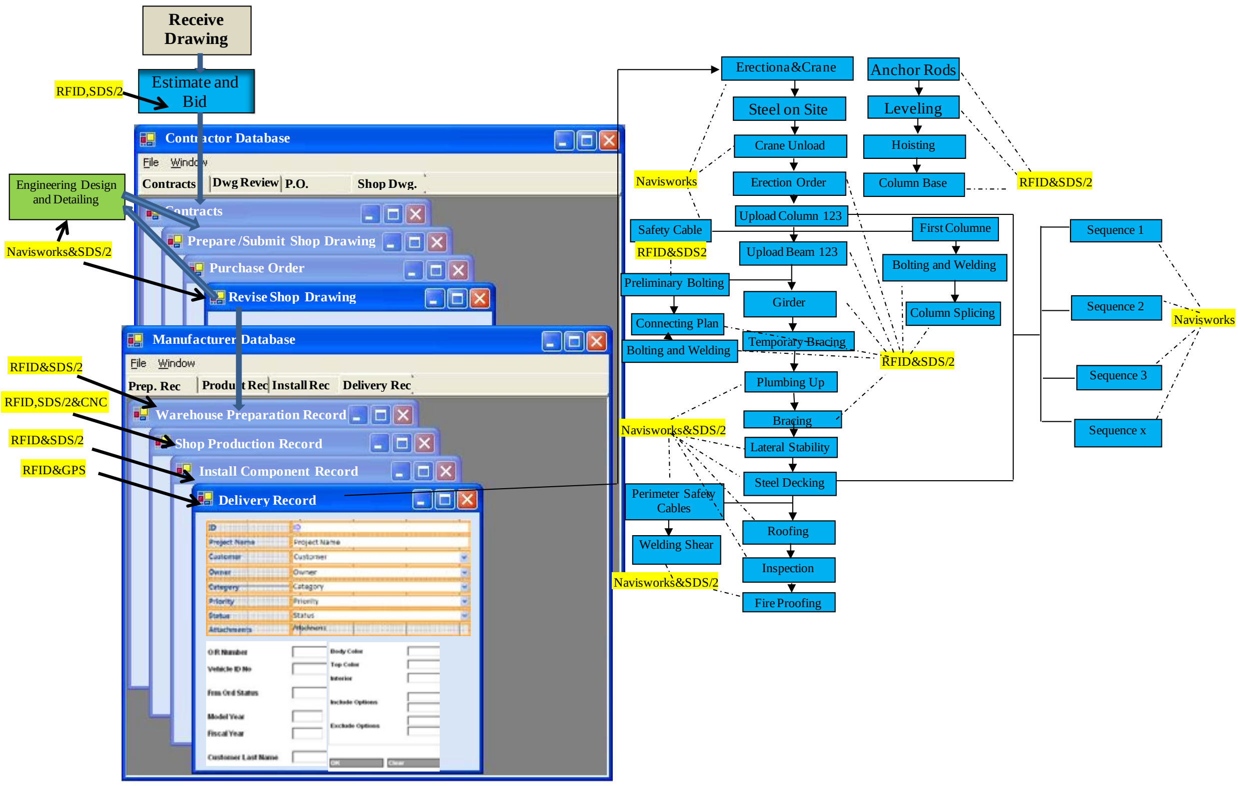

FIG. 7: *BIM work flow for NQS Company fabrication and erection process.*

8.2 Erection sequence analysis –optimized schedule

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, which is forwarded to the fabricator. It takes at least two work days for a new schedule to be approved. There has to be 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 the 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 the 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 an optimal steel erection order can be determined.

Fig. 8 shows the work flow of a construction project. It compares the differences between the traditional project control methods and the 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 2D drawings, looking for right dimensions, or searching for connections or correct parts.

The BIM decision model can bring three major benefits to the AEC industry. The first benefit is the time saving for scheduling and planning. Fig. 8 shows a big gap 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 savings in the space required for steel storage. When using the BIM/RFID Framework, the just-in-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, and BIM with Total Quality Control (TQC) and Flexibility Production System (FPS) to improve the steel structure construction productivity.

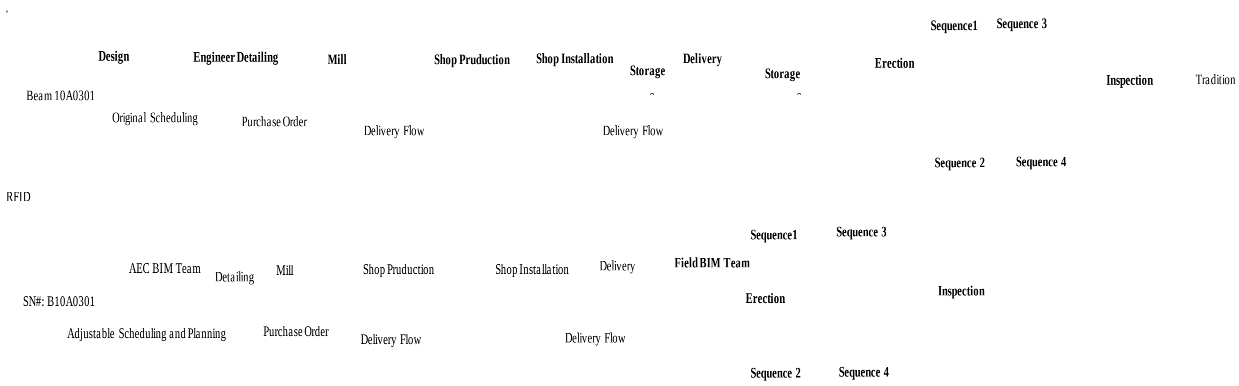

FIG. 8: Traditional construction method versus BIM/RFID Framework schedule and delivery flow.

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 system. Similar to the CNC system, it can automatically design the piece cutting plan for a given sheet of metal to have an optimized result for material savings.

By using the BIM database information, the VR 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. In the BIM/RFID Framework, the schedule sequence is affected by variables 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 it affects the job situation and condition.

Fig. 9 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.

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 had one minor accident during its operation. Crane B is used for sequences 2, 4 and 6 which is the east parts floor 1 and floor 3, and the west side of floor 2 which crosses 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 delayed 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 easier to diagnose and it can be improved.

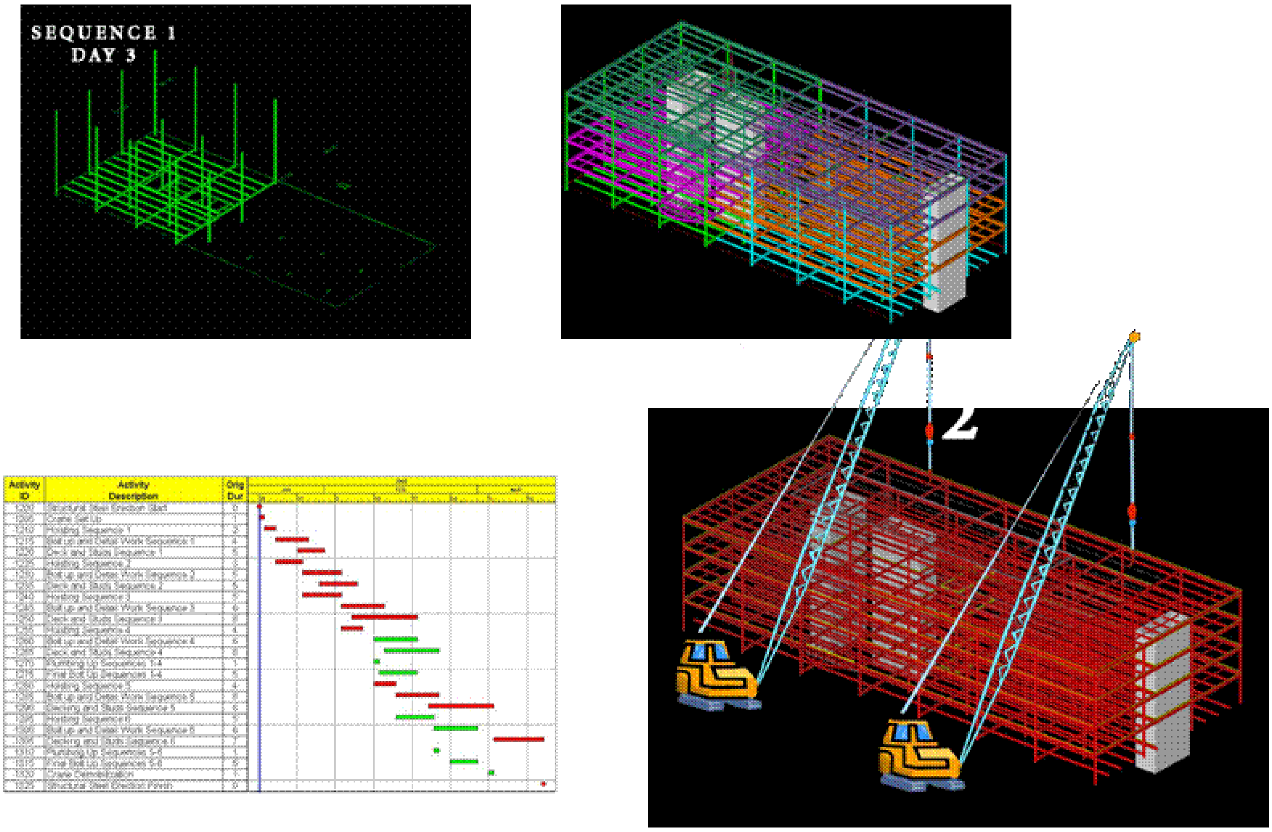

FIG. 9: The simulation of BIM/RFID Framework operation for steel structure erection job sequences (AISC 2005)

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 the planning change. The erection order change can help crane B do the easy hoisting while crane A can handle most of the complicated members. Planning changes 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.

9. CONCLUSION AND FUTURE STUDIES

9.1 Research summary and contribution

This research proposes a model that combines Building Information Modeling (BIM), Radio Frequency Identification (RFID), and Virtual Reality (VR) Simulation. The model focuses on steel fabrication and site steel erection. The program is based on a multi-purpose model, which uses RFID 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 approach 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 for helping AEC professionals make decisions by using the erection progress shown on the BIM control and testing system.

9.2 Limitations and barriers of the BIM/RFID VR Framework

9.2.1 Data safety problem

The concern for 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.

9.2.2 Data reliability

BIM tools are marketed by different companies, designers, programmers, and software developers. 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 programs may have some conflicts as well.

9.3 Recommendations for Future Research

Future development work for this research will include simplifying and standardizing the system operations so that the 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 and jobsite offices.

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