

THESIS

THE POTENTIAL OF INTEGRATED PROJECT DELIVERY IN GREENING THE  
STRUCTURAL STEEL DELIVERY PROCESS

Submitted by

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## ABSTRACT

### THE POTENTIAL OF INTEGRATED PROJECT DELIVERY IN GREENING THE STRUCTURAL STEEL DELIVERY PROCESS

The structural steel industry provides the world with one of the fundamental construction materials, steel, and in the process produces negative byproducts. While the steel industry has made commendable progress to reduce their environmental impacts, there remains room for improvement, particularly in the delivery process of structural steel. Currently, the majority of the structural steel industry uses traditional delivery methods to execute design, engineering, detailing, fabrication, and erection.

Construction industry professionals are realizing the drawbacks of traditional delivery systems and are now exploring the opportunities provided by Integrated Project Delivery (IPD).

The researcher studied the potential that IPD could have on lessening the environmental impacts of the steel industry through a case study of the National Renewable Energy Laboratory (NREL) Research Support Facilities (RSF) project. Data was collected through interviews with NREL RSF project team members. Data analysis revealed thirty opportunities for improvement to reduce the environmental impacts associated with the delivery of structural steel.

Overarching process recommendations expand on the need to establish direct lines of communication among the structural steel team, ensure early involvement of the erector and fabricator in the steel design phase, and utilize appropriate technology.

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## TABLE OF CONTENTS

Chapter 1: Introduction .....	1
1.1 Problem Statement, Purpose, and Scope.....	3
1.2 Research Questions .....	5
Chapter 2: Literature Review .....	6
2.1 Traditional Delivery Methods .....	6
2.1.1 Design-Bid-Build .....	6
2.1.2 Construction Management .....	8
2.1.3 Design-Build .....	9
2.2 Integrated Project Delivery .....	11
2.2.1 Benefits of Integrated Project Delivery .....	15
2.2.2 Challenges of Integrated Project Delivery .....	17
2.3 The Structural Steel Industry, Environmental Impacts, & Sustainability.....	18
2.4 Greening the Structural Steel Industry through Integrated Project Delivery .....	23
Chapter 3: Methodology .....	28
3.1 Introduction .....	28
3.2 Population .....	30
3.3 Obtaining Interviews.....	31
3.4 Method of Data Collection.....	31
3.5 Treatment of Data and Analysis.....	33
Chapter 4: Findings.....	35
4.1 Individual Interviews.....	36
4.1.1 Opportunities for improvement.....	38
4.2 Focus Group Session.....	67
4.2.1 Process recommendation #1: Establish direct lines of communication among the structural steel team.....	68

4.2.2 Process recommendation #2: Ensure early involvement of the erection team and fabrication team in the steel design phase .....	72
4.2.3 Process recommendation #3: Utilize appropriate technology .....	76
Chapter 5: Conclusions .....	79
5.1 Research Summary .....	79
5.1.1 Research problem and research questions.....	79
5.1.2 Methodology .....	80
5.1.3 Findings.....	81
5.2 Moving Towards Integrated Project Delivery .....	86
5.2.1 Early involvement of key participants .....	87
5.2.2 Intensified planning .....	88
5.2.3 Open communication .....	89
5.2.4 Appropriate technology .....	90
5.2.5 Mutual respect and trust.....	91
5.2.6 Remaining principles .....	92
5.3 Future Research.....	93
References.....	96
Appendix I – Email Recruitment Email .....	99
Appendix II – Individual Interview Questions .....	102
Appendix III – Summary of Individual Interviews .....	106
Appendix IV – Focus Group Session Agenda .....	111
Appendix V – Partial Transcription of Individual Interviews .....	113
Appendix VI – Partial Transcription of Focus Group Session .....	130

## LIST OF TABLES AND FIGURES

Table 1. NREL RSF project's structural steel emissions by life cycle phase .....	23
Table 2. Interview participants from the NREL Research Facilities Project team ....	30
Table 3. Number of opportunities for improvement by theme .....	36
Table 4. Individual interview participants, associated companies, and fields of service .....	37
Table 5. Focus group session participants, associated companies, and fields of Service .....	68
Figure 1. Design-Bid-Build illustration .....	7
Figure 2. Construction Management at Risk illustration .....	9
Figure 3. Design-Build illustration .....	10
Figure 4. Macleamy Curve .....	16
Figure 5. Comparison of project phases between a traditional delivery method and an integrated delivery .....	25
Figure 6. Contractual arrangement for the structural steel delivery of the NREL project .....	46
Figure 7. National Renewable Energy Laboratory Research Facilities Project site infrastructure plan .....	51
Figure 8. Proposed integrated steel delivery model .....	61
Figure 9. Early involvement diagram .....	74

## **Chapter 1: Introduction**

The recent peril of global climate change has brought the fragile state of our environment to the forefront of societal concerns (Steel Construction Sector Sustainability Committee, 2002). Organizations such as the Intergovernmental Panel on Climate Change, the United States Green Building Council (USGBC), and United States Department of Energy all point to the construction industry as having a direct impact on our environment. Indeed, in the United States, buildings account for 39% of energy use, 38% of all carbon dioxide emissions, and 30% of waste output (United States Green Building Council, 2009). Statistics such as these bare a heavy responsibility on the building community to rise to the challenge and take measures to reduce the negative impacts of the construction industry.

The Structural Steel industry provides the world with one of the fundamental construction materials, steel. Steel is often praised as a “green” material because it is 100% recyclable, and indeed, it is one of the most commonly recycled materials in the United States (Berman, 2000). However, the production and recycling of steel produces negative byproducts such as greenhouse gas emissions, energy consumption, and consumes nonrenewable resources as part of material production. While the steel industry has made commendable progress over the past twenty-five years to reduce their environmental impacts (World Steel Association, 2008), there remains room for improvement, particularly in the delivery method of structural steel. For the purposes of

this study, steel delivery method refers to all stages of a project including design, engineering, detailing, fabrication, and erection (Berman, 2000). Gary Berman (2000), a licensed professional engineer with more than twenty-two years of experience in structural steel industry, agrees that there is room for improvement in the delivery of steel. He states, “The answer lies in the process from design through erection, the number and types of parties involved in the process, and the ease and speed at which changes can be accommodated” (p.9). Each of these factors is highly influenced by the chosen delivery method.

Currently, the majority of the structural steel industry uses traditional delivery methods to execute design. Traditional delivery methods include design-bid-build, construction management at-risk, and design-build. Construction industry professionals are realizing the drawbacks of such systems, such as adversarial relationships between project team members, delays in design and construction, and increased costs. The industry is now exploring some of the opportunities provided by a newly developed delivery method, Integrated Project Delivery (IPD). Opportunities include involving project team members early in a project and utilizing Building Information Modeling (BIM) (Cross, 2008). IPD is most commonly defined as, “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication, and construction” (AIA California Council & McGraw Hill Construction, 2007). By using Integrated Project Delivery, the structural steel industry has the potential to create less waste, such as reducing the amount of excess material produced, cutting back on erection errors, and

requiring less Requests for Information (RFI). A vital component of achieving less waste, and thus less of an environmental impact, is to include all key and secondary stakeholders in the design phase, a guiding principle of Integrated Project Delivery. Key stakeholders are defined as the owner, architect, and constructor. Secondary stakeholders include the primary design consultants and subcontractors such as the steel fabricator, erector, engineer, and detailer (AIA National & AIA California Council, 2007). There has been a limited amount of research conducted on the value of including secondary stakeholders, particularly the fabricator and erector, in the design phase of structural steel. Therefore, this study will research the value of including secondary stakeholders (i.e. the fabricator and erector) in the design phase of structural steel.

### **1.1 Problem Statement, Purpose, and Scope**

There is a need to reduce the impact that the structural steel industry has on the environment. The Structural Steel industry provides the world with one of the fundamental construction materials, steel, yet, produces negative byproducts such as greenhouse gas emissions, energy consumption, and consumes nonrenewable resources as part of material production. While the steel industry has made commendable progress over the past twenty-five years to reduce their environmental impacts (World Steel Association, 2008), there remains room for improvement, particularly in the delivery method of structural steel.

This study will determine whether this can be accomplished by investigating the value of including secondary stakeholders in the design phase of structural steel. The researcher will base this study on a current National Renewable Energy Laboratory (NREL) Research Support Facilities project, a 222,000 square foot office structure

located at NREL's South Table Mountain campus in Golden, Colorado (National Renewable Energy Laboratory, 2010a).

The National Renewable Energy Laboratory, in partnership with the United States Department of Energy (DOE), exists as a research and development facility to further the nation's energy goals (National Renewable Energy Laboratory, 2009). The NREL Research Support Facilities project was designed to become a significant green building, targeting LEED Platinum or better, and is scheduled for completion in summer 2010. As part of a Design-Build contract, the project team is reported to have used an integrated design process by including mechanical engineers and daylighting consultants early in the process (National Renewable Energy Laboratory, 2010c). Practicing integrated design is a vital prerequisite for a project team to move towards adopting an Integrated Project Delivery method (AIA National & AIA California Council, 2007). Therefore, the scope of this study will focus solely on the NREL Research Support Facilities project because of the project team's integrated design approach.

By basing this study on the design phase of the NREL Research Support Facilities project, results will provide information that will allow the structural steel industry to better understand current processes and possible opportunities for reducing the environmental impacts associated with the delivery of structural steel. This information will also lead to the identification of process recommendations for adopting an Integrated Project Delivery method for a possible future NREL building as well as other buildings that rely heavily on steel.

## **1.2 Research Questions**

This study aims to answer the following research questions:

1. What are the opportunities and efficiencies that exist as a result of using Integrated Project Delivery (IPD) versus a traditional delivery method for the NREL Research Support Facilities project?
2. What are the benefits of including secondary stakeholders in the design phase of structural steel for the NREL Research Support Facilities project?

## **Chapter 2: Literature Review**

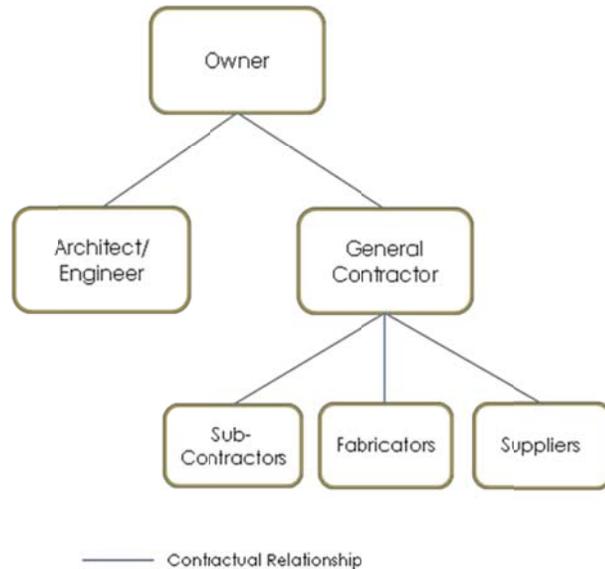
### **2.1 Traditional Delivery Methods**

While there are several types of delivery methods, Design-bid-build, Construction Manager at-Risk, and Design-Build are the three most commonly used traditional delivery methods. Each operates within a unique system and the decision to go with one over the other is evaluated on a project-by-project basis, while taking into consideration, at a minimum, project requirements, cost, and schedule.

#### **2.1.1 Design-Bid-Build.**

This first of the three, Design-Bid-Build (DBB), has been the most common delivery method used for over a century (The McGraw-Hill Companies, 2003). DBB includes three key stakeholders, the owner, designer and builder. DBB is a stepped method, in which construction does not happen until after design is complete. Furthermore, the designer (usually an architect) and builder (usually a general contractor) are hired by the owner as separate entities with little communication between the two. Both the architecture team and construction team report to the owner through independent lines of communication. Figure 1 illustrates the relationships among key players in DBB.

The owner hires an architect to develop the design and specifications and then requests bids from the general contractors. Bids are based on cost most of the time, as the



**Figure 1. Design-Bid-Build illustration**

contract will go to the lowest bidder. The awarded price includes cost for labor, materials, overhead, and profit (The McGraw-Hill Companies, 2003).

Design-Bid-Build is used most often on public works projects. A benefit of DBB is that the bidding process is not restricted to a specific number of companies. DBB allows smaller, new, or less-known construction companies to compete on an equal playing field with the top companies.

Design-Bid-Build is criticized for creating adversarial relationships between the architect and general contractor since the contractor does not have input on the design. DBB is also criticized for the long amount of time needed for design and construction. The steps are performed in an order that often causes delays and increased costs. For example, the architect is responsible to develop a cost estimate for the design even though actual project costs are not truly determined until after the project has gone to bid. If there is a stark difference between the two prices, this can set the project back several

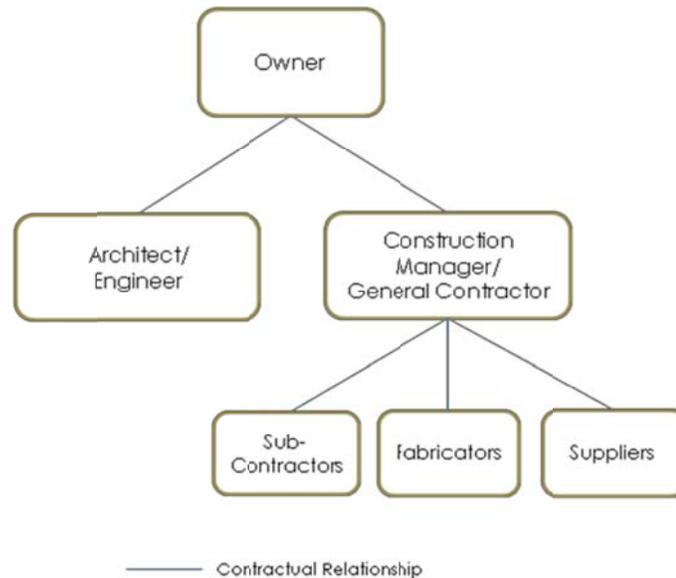
steps (Mahdi & Alreshaid, 2005). Furthermore, DBB can often result in higher construction costs due to the fast-paced nature of pulling bids together. Mistakes in plans and specifications are often made (Fisk & Reynolds, 2006).

### **2.1.2 Construction Management.**

A second traditional delivery method is known as Construction Management at Risk (CM at Risk). This system was developed by the General Services Administration to be used for federal building construction. CM at Risk is more widely used today, however, for any number of project types (Fisk & Reynolds, 2006).

CM at Risk project teams consist of the owner, designer, and constructor. The designer (architect/engineer) is responsible for the design of the project, and a separate construction management firm (known as the construction manager) is hired to serve as a general contractor. The construction manager (CM) will act as a consultant during the design process and then change roles to oversee construction once a guaranteed maximum price is established and awarded. Usually, the CM will hire out construction work and act as a manager (The McGraw-Hill Companies, 2003). See Figure 2 for an illustration of the contractual relationships.

One benefit of CM at Risk is that the construction manager is involved in the design process offering input towards the design, cost, and schedule. This can allow for fewer complications during the latter half of a project, as the architect is not estimating costs without the CM's input. Design input from the contractor addresses one of the main criticisms of Design-Bid-Build. Furthermore, because the CM and designer interact throughout the project, the design and construction phases do not need to be completely



**Figure 2. Construction Management at Risk illustration.**

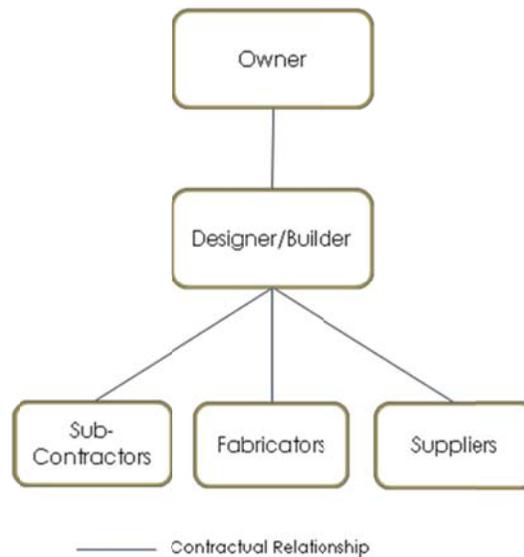
separate of each other. Construction can begin without a complete design, as design and construction move parallel to each other at times.

A drawback of CM at Risk is the switch in roles for the construction manager. The CM plays an advisory role during the design phase but becomes part of a standard contractual role once awarded general contractor. This can lead to tensions between stakeholders over construction cost, schedule, and quality. Furthermore, while CM at Risk is faster than DBB it is still slower than other delivery methods (Mahdi & Alreshaid, 2005).

### **2.1.3 Design-Build.**

The last of the triad of traditional delivery methods is Design-Build (D/B). This method has become increasingly popular, as many believe that it compensates for several of the shortcomings of other delivery methods (Mahdi & Alreshaid, 2005). The owner benefits by doing business with only one entity (and therefore uses one contract) that

performs design and construction services from project inception to closeout. Similar to Construction Management at Risk, design and construction are done parallel to each other since there is one entity performing both services. Construction can be phased as the design is being developed. The Design-Build entity may be a single firm or joint venture (Simmons, 2007). See Figure 3 for an illustration of the relationship among key players.



**Figure 3. Design-Build illustration.**

Whereas other delivery methods result in adversarial relationships between the architect and constructor (mostly due to hierarchical lines of communication and separate contracts), Design-Build firms house both parties and form a single source of responsibility. This speeds up dispute resolution and makes it much more necessary. Furthermore, the owner will not be dragged into dispute resolution since the architect and constructor have direct lines of communication. Another advantage is that the architect and constructor work together from the very beginning of a project. Early collaboration

can have many benefits, such as enhanced constructability and fewer change orders (The McGraw-Hill Companies, 2003).

The most commonly cited disadvantage of Design-Build is that it does not fit within many state laws concerning public funds. Several state laws require that a contractor be obtained through a competitive bidding process and that the job be awarded to the lowest bidder; hence the common use of Design-Bid-Build (Fisk & Reynolds, 2006). While the Design-Build selection process does allow for a designer and constructor to be selected based on a range of qualifications, Design-Build nonetheless does not adhere to many state laws.

## **2.2 Integrated Project Delivery**

Integrated Project Delivery (IPD) is a recent development in the construction industry that encompasses sustainability, productivity, technology, and culture change into one delivery method. The most documented definition of IPD is, “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication, and construction” (AIA California Council & McGraw Hill Construction, 2007). While IPD has yet to be fully incorporated into mainstream practice, there is a growing collection of literature and case studies on the benefits of IPD as well as basic language and guidelines for utilizing IPD as a delivery method.

Construction industry professionals developed Integrated Project Delivery in an attempt to address the drawbacks of traditional delivery methods. The American Institute of Architects (2007) describes the need by stating:

It may set all who believe there is a better way to deliver projects on a path to transform the status quo of fragmented processes yielding outcomes below expectations to a collaborative, value-based process delivering high-outcome results to the entire building team. (p.1).

Since IPD is a recently developed concept, literature on the topic is general in nature. The limited scope of literature includes definitions of and guidelines for IPD, a handful of case studies about the challenges, process, and benefits of IPD, and some outside opinions of IPD from industry professionals (AIA California Council & AIA National, 2009; AIA California Council & McGraw Hill Construction, 2007; AIA National & AIA California Council, 2007).

IPD is based on nine guiding principles. Each principle and a bulleted summary is listed below.

1. Mutual Respect and Trust

- All team members (owner, designer, constructor, consultants, subcontractors and suppliers) value collaboration.
- All team members commit to working towards the best interests of the project.

2. Mutual Benefit and Reward

- IPD benefits all participants and team members.
- Compensation and incentives are based on the value an organization adds to achieving the project goals.

3. Collaborative Innovation and Decision Making

- Collaborative innovation occurs when all participants exchange ideas without restraint.
- The project team assesses key decisions.

- Decisions are to be made unanimously when practical and feasible.
4. Early Involvement of Key Participants
    - Decision-making is enhanced by considering the knowledge and expertise of all team members.
    - The early involvement of key participants is most effective during the beginning phases of a project, as this is when collaborative decisions have the most impact.
  5. Early Goal Definition
    - Goals are defined early in the project.
    - Team members must agree upon and respect project goals.
    - Project goals shape the basis of individual team member objectives and values.
  6. Intensified Planning
    - Increased planning efforts result in greater efficiencies and savings, such as cost and schedule, during project completion.
  7. Open Communication
    - Team performance is dependent upon receptive and honest communication between all participants.
    - Responsibilities are assigned with the understanding that team members practice a no-blame culture. Well-defined and allocated responsibilities allow problems to be identified and solved more effectively, rather than resorting to liability.
  8. Appropriate Technology
    - Integrated projects can be greatly aided by advanced technologies.
    - Technologies are brought on at the start of a project and are utilized to improve functionality and simplicity, and must be operable between project disciplines.
    - Building Information Modeling (BIM) is highly suggested, although not

absolutely necessary, as a tool to execute IPD. BIM is a 3D computer modeling program that allows a project to be built electronically first before physically building it on site. A detailed computer model allows the project team to identify errors, assess the constructability of a project, and modify the plans with the goal of reducing and potentially avoiding errors on site. BIM requires an integrated design process, and therefore pairs well with IPD (National Institute of Building Sciences, 2007).

#### 9. Organization and Leadership

- Leadership for certain tasks is assigned to the best-suited team member depending on the type of work and requirements.
- Team member roles are clearly defined in a way that supports open communication and risk taking.

All literature on IPD is in agreement that in order for IPD to truly be successful, the project team must adhere to all nine principles throughout the entire project.

Understanding the principles of IPD is fundamental to assembling a project team that will adhere to the ideals of the delivery method. There are essentially four steps to assembling an Integrated Project Delivery team (AIA California Council & McGraw Hill Construction, 2007):

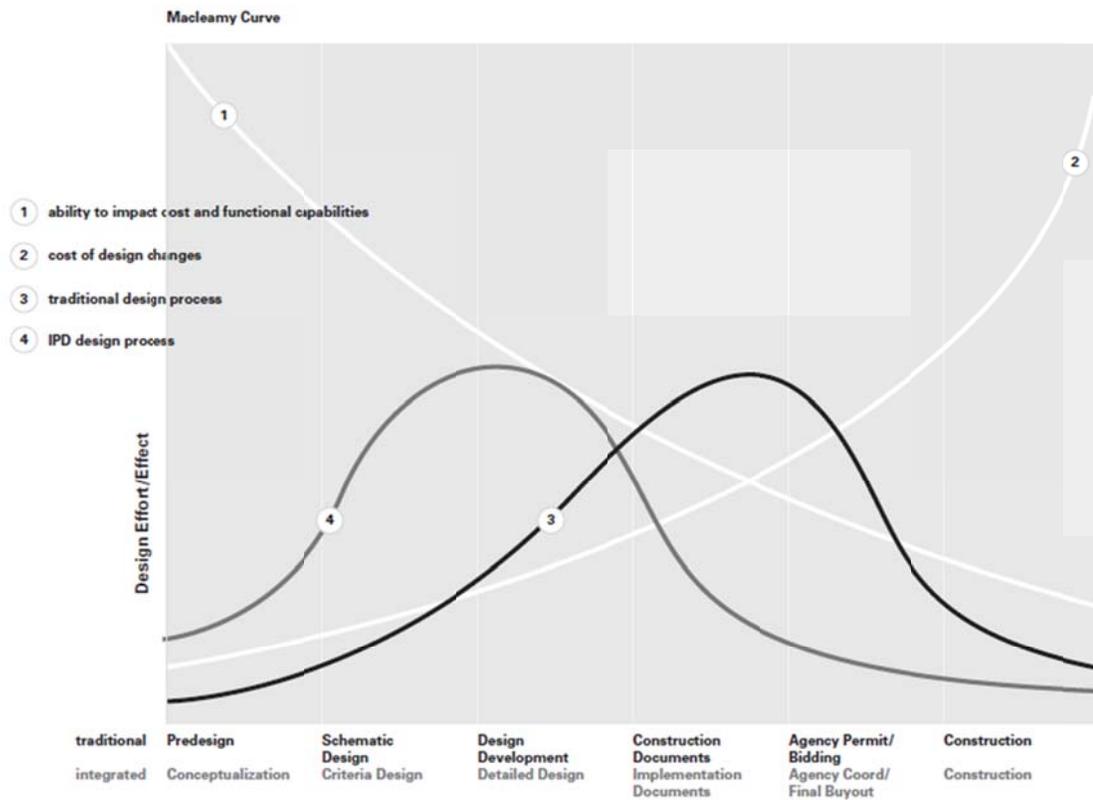
1. Brainstorm and Identify Key Participants.
  - The AIA Council & McGraw Hill (2007) suggests considering the involvement of the following participants, “Owner, Operator/User, Designers (architects/engineers), Contractors, Subcontractors, Suppliers, Equipment manufacturers, Systems integrators, and Lenders.”
  - Glick and Guggemos (2009) suggest including secondary stakeholders, such as “insurance companies, bankers, regulatory agencies, utility providers, or anyone else that may have an interest in the project.” (p.1).
2. Interview Team Members
  - Interview possible team members based upon their qualifications and commitment to collaborative delivery methods.
3. Determine Business Structure
  - Evaluate the most suitable business structure for the particular project.
  - Take into account the requests and limitations of each team member.
4. Write Project Agreements
  - At a minimum, agreements should include project roles, responsibilities, risk allocation, and compensation.

Ideally, at the end of Step 4, one will have developed an Integrated Project Delivery team (AIA California Council & McGraw Hill Construction, 2007).

### **2.2.1 Benefits of Integrated Project Delivery.**

When it comes time to the actual delivery process of a project, this is where IPD separates itself the most from traditional delivery methods. Because IPD defines itself based on early collaboration of all team members and executes project design through

Building Information Modeling (BIM), the design is at a higher level of completion before the traditional Construction Documents phase. Developing a more comprehensive design before the Construction Documents phase led AIA to redefine the timeline and objectives for traditional delivery phases. Figure 1 illustrates the different timelines, design effects based on amount of effort, ability to impact cost and functional capabilities, and cost of design changes between a traditional delivery process and an IPD process. The chart also includes traditional phase names in bold and IPD phase names below in grey.



**Figure 4. Macleanmy Curve (AIA National & AIA California Council, 2007).**

Based on Figure 4, it becomes clear that an increased amount of design effort during the Conceptualization, Criteria Design, and Detailed Design phases result in less

design effort during the latter half of a project, the Implementation Documents, Agency Coordination/Final Buyout, and Construction phases.

According to Figure 4, less design effort and thus less design changes towards the end of a project is highly beneficial to a project's budget and schedule. The ability to impact cost and functional capabilities greatly decreases towards the end of a project's life, and the cost of design changes greatly increases towards the end of a project's life. IPD appropriately assumes the greatest amount of design effort towards the beginning of the project, which allows team members to collaborate, communicate, and be innovative while the project budget and schedule is still relatively flexible and can absorb change better than towards the latter half of a project's life. AIA National and the AIA California Council (2007) conclude that this approach will increase the efficiency of the construction phase and possibly decrease the amount of time needed for construction.

### **2.2.2 Challenges of Integrated Project Delivery.**

Although Integrated Project Delivery is still a new concept (in relation to other delivery methods), the literature still cites a handful of challenges to adopting IPD. One of IPD's biggest barriers is deeply rooted within the hierarchical structure of traditional delivery methods. Although collaboration occurs in varying degrees across all traditional delivery methods, construction industry professionals are accustomed to strict, and sometimes limited, lines of communication and a linear design method that does not promote integration between the architect, engineer, and constructor. AIA National and the AIA California Council (2007) believe that the owner has the greatest potential to restrain collaboration among team members. The owner is in a position of authority and

often does not require thorough input from all contracted parties to move forward with a decision.

Another challenge to implementing IPD is ensuring common language among all contracts. It is common that the owner will have separate contracts with the designer, constructor, and sometimes multiple prime contractors. Since IPD requires that the project team develop common procedures and performance requirements, the owner will have to ensure that the contract language is consistent among all agreements and/or the general conditions (AIA National & AIA California Council, 2007).

A third challenge is in the small amount of literature that exists about IPD compared to other delivery methods. Many professionals are still not convinced on the full value and benefit of IPD and look to case studies and hard data to push them one way or another. While there is some data that predicts the outcomes of using IPD, there are very few case studies with actual data. The largest attempt at compiling case studies was made by the American Institute of Architects (AIA) (2009) in the report, “Experiences in Collaboration: On the Path to IPD”. In the absence of abundant case studies, AIA California Council’s IPD committee studied several projects that were using components of IPD. Practitioners were gathered together to discuss lessons they learned from budgeting, using a collaborative design process, relying on BIM, and other aspects of IPD. Not only is there a lack of convincing hard data available on IPD, but the experiences quoted are based on pieces of IPD rather than a project that has incorporated all nine principles from project inception to close out.

### **2.3 The Structural Steel Industry, Environmental Impacts, & Sustainability**

The design process of a project is largely determined by the chosen project

delivery method. It has been noted that construction industry professionals are realizing the drawbacks of traditional delivery methods. According to John Cross (2008), Vice President of the American Institute of Steel Construction (AISC), “significant cost and schedule savings coupled with enhanced project quality has encouraged project owners to embrace a project delivery methodology outside the design-bid-build comfort zone” (p.22). One specific industry, the Structural Steel industry has begun to move away from certain aspects of traditional delivery methods and is exploring the benefits of integrated design and Building Information Modeling (BIM) in an effort to lessen the industry’s environmental impacts (Cross, 2008).

The structural steel industry is a large contributor to the overall construction industry, as steel is a fundamental material for construction projects. The industry does not come without its share of environmental impacts, however, such as carbon emissions, natural resource depletion, and water consumption. Internationally, there has been a large effort to decrease the environmental impacts of steel. The Steel Construction Sector Sustainability Committee (SCSSC) (2002) released a report, *Sustainable Steel Construction: Building a Better Future*, which outlines initiatives to protect the environment, employees, and the communities that are affected by the steel industry. Also in 2002, the World Steel Association (WSA) established a policy on sustainable development, which reinforces the directives of the WSA report and accounts for more recent sustainability efforts (World Steel Association, 2008).

More specifically, there is a strong desire within the structural steel industry to have less of a negative environmental impact. This is evident in the progress the industry has made within the past twenty-five years. For example, the transformation from using blast furnace technology, or a basic oxygen furnace, to an electric arc furnace (EAF)

process in order to produce steel has produced significant environmental improvements. The problem is that blast furnace technology still demands the mining of natural resources. EAF technology, on the other hand, allows the industry to recycle steel and iron scraps that would otherwise be considered waste. Structural steel mills are now able to divert large amounts of waste from landfills by using car parts, appliances, steel from demolished buildings, industrial scrap, and steel scrap from curbside recycling programs in the production of structural steel. Domestically produced structural steel averages a 90% recycled content rate and the rate of recycled steel from deconstruction is at 98% (Cross, 2008). The structural steel industry has also reduced greenhouse gas emissions and energy usage over the past thirty years. Admirably, the structural steel industry has taken great responsibility in their role as a leading producer of a construction material and has decreased the environmental impacts of several phases of steel production.

The structural steel industry has also been exploring opportunities for efficiencies among delivery methods in an effort to consider the environmental impacts of all phases as well as keep up with international competition and increasingly stricter environmental regulations (Steel Construction Sector Sustainability Committee, 2002). The structural steel industry is beginning to embrace certain aspects of Design-Build such as collaboration among team members and an integrated design process. Integration equates involving team members that would typically be considered consultants to join the project team as contractual members. The structural steel erector often joins a project team as a sub-contractor and is therefore not usually included in the early design phases of a project. However, changes made during the erection phase are generally more expensive and problematic than those made during engineering, detailing, or fabrication (Berman, 2000). Involving the erector early on in a project might lead to more informed design

decisions that could prevent changes during erection.

Structural steel fabricators are increasingly brought on to projects in the design phase as opposed to after Construction Documents are complete. This was the case for Palomar Medical Center West (PMC West), a 755,000 square-foot hospital in California. The PMC West project team involved the structural steel fabricator early on in the project and realized a more efficient design, cost savings, and a condensed construction schedule as a result (Zeidan, et al., 2010). More specifically, early involvement of the steel fabricator can lead to approximately 20% cost savings and can condense the project schedule by up to 40% (Cross, 2008). Cross (2008) further mentions several attributes of including the steel fabricator early in design. He states:

The steel fabricator is well prepared to give guidance on minimizing weld requirements to reduce electric consumption, delivery scheduling to reduce wait times, balancing the tradeoffs between additional material and the use of cambering, doublers and stiffeners, optimizing the project flow based on shop configurations, enhanced erection efficiencies and evaluating various framing and bracing options from an environmental impact perspective. (p.27).

The structural steel industry is also exploring the benefits of incorporating Building Information Modeling, claiming to be a leader in applying BIM and virtual construction technologies (Cross, 2008). BIM allows a project to be built twice - first virtually and then built for a second time in the field. In order to realize the full benefits of BIM, it is essential that all members are engaged to make early design decisions in an attempt to create the best virtual product possible. This should result in as few errors and changes as possible when it comes time to build the physical model. The structural steel industry has documented that BIM allows the steel fabricator to provide more accurate offsite fabrication, which leads to a simpler and quicker assembly in the field due to the aid of an accurate building model. Cross (2008) argues that BIM will improve

sustainability efforts because one can gather a more reliable estimate of a building's impact by basing it on the actual design of a building rather than basing it on selected structural assemblies. By utilizing a virtual design, the project team can simulate multiple scenarios in an effort to decrease the environmental impacts of a structure (Cross, 2008).

Although the efforts of the structural steel industry to lessen their environmental impact is worthy of praise, there remain areas within the delivery process of structural steel that are only beginning to be explored. For example, a recent study conducted at Colorado State University quantified the environmental impacts of the material production, fabrication phase, and erection phase of the steel frame of the National Renewable Energy Laboratory (NREL) Research Support Facilities project (RSF). This study defined the steel frame as the beams, columns, joists, girders, stair assemblies, and decking. Researchers defined the three phases as follows:

*Material production* includes the extraction and refinement of raw materials into useable commodities, such as steel. *Fabrication* consists of transporting materials to all activities at the various fabrication plants that convert standard steel shapes into specific building components and includes the emissions produced by generating electricity for the plants. *Erection* includes transportation of materials from the fabricator to the jobsite, transportation of workers and equipment to the jobsite, onsite equipment usage for erection and detailing, and the indirect impacts of producing the electricity and fuel used during construction (Guggemos, Plaut, Bergstrom, Gotthelf, & Haney, 2010).

Table 1 illustrates the contribution each phase is responsible for as they relate to five significant air pollutants (carbon dioxide, sulfur dioxide, carbon monoxide, nitrogen oxide, and particulate matter) and embodied energy (Guggemos, Plaut, Bergstrom, Gotthelf, Haney, et al., 2010).

**Table 1. NREL RSF project's structural steel emissions by life cycle phase (Guggemos, Plaut, Bergstrom, Gotthelf, Haney, et al., 2010).**

	CO <sub>2</sub> (kg)	SO <sub>x</sub> (kg)	CO (kg)	NO <sub>x</sub> (kg)	PM <sub>10</sub> (kg)	Energy (MJ)
Material production (% of Total)	894,000 59%	2,170 57%	12,800 91%	1,360 32%	1,080 89%	11,500,000 58%
Fabrication	277,000 18%	1,240 33%	494 3%	868 20%	49.0 4%	3,640,000 18%
Erection	342,000 23%	388 10%	823 6%	2,060 48%	83.5 7%	4,740,000 24%
<b>Total</b>	<b>1,510,000</b>	<b>3,800</b>	<b>14,100</b>	<b>4,230</b>	<b>1,210</b>	<b>19,900,000</b>

Given the implications of only a portion of the steel delivery phases, a comprehensive approach to improving the efficiency of all structural steel delivery phases is imperative.

#### **2.4 Greening the Structural Steel Industry through Integrated Project Delivery**

Integrated Project Delivery is equipped with numerous tools to take the structural steel industry to the next level of improving efficiency within their delivery process. While the article, *Design-Build, Building Information Modeling and Sustainability: Structural Steel and the Emerging Future of Design and Construction*, presents convincing data of moving towards IPD, it stands alone. There are no other known sources that document an attempt towards integrating IPD within the structural steel industry.

Project team collaboration and early involvement of stakeholders are IPD principles for good reason. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) promotes interaction among team players as a way to reach increased energy efficiencies. The Leadership in Energy and Environmental Design (LEED) green building rating system also encourages collaboration among all team members (AIA National & AIA California Council, 2007). Building professionals are paying attention to the data and realizing results from practicing integrated processes.

Involving key project team members as early as possible in the design process could greatly benefit the Structural Steel Industry. Figure 5 compares the phases at which different project participants become involved between a traditional design process and an integrated design process.

As Figure 5 illustrates, IPD suggests bringing team members other than the owner and designer on to a project much earlier than that of a traditional design process. Other team members may include government agencies, design consultants, constructors, and trade constructors. Because there is an increased effort at the early stages of a project, results may lead to an increase in efficiency of the construction phase and possibly a decrease in the amount of time needed for construction (AIA National & AIA California Council, 2007). A more efficient and possibly shorter construction phase could have great implications for lessening the environmental impact of the structural steel design process.

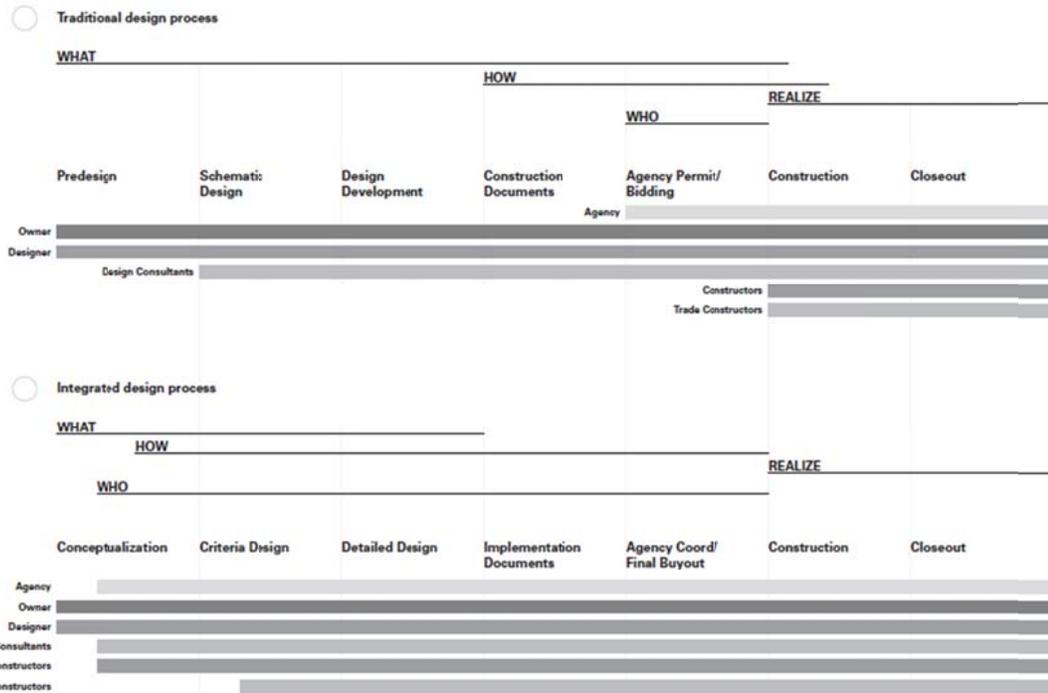


Figure 5. Comparison of project phases between a traditional delivery method and an integrated delivery method (AIA National & AIA California Council, 2007).

Greater efficiencies could result in less wasted materials such as office paper, transportation fuels, and the actual steel itself. Additionally, less wasted materials could equate to cost savings.

Early involvement will also allow for design input from all key players. Too often, the expertise of project team members will be sought in isolation at disjointed points throughout a project (7 Group & Reed, 2009). Rather, bringing project team members together at the beginning of a project can have multiple benefits. For example, the constructor can strengthen pre-construction planning, understand the design more thoroughly (than if receiving the design closer to the Construction phase), provide feedback on the constructability of proposed designs, have more time to work through construction sequencing, and assist with cost estimates. The contractor can also assist

with reaching a project's sustainability goals by suggesting environmentally friendly materials, water efficiency techniques, and efficient transportation methods (Son, Kim, Chong, & Chou, 2009). Through these activities, the constructor will help to ensure a feasible design, which could increase the chance of meeting the project budget and schedule and decrease the chance for lost time and materials as it relates to construction. Conversely, the designer can directly benefit from the constructor's contributions by having the opportunity to work with precise budget estimates and gain direct feedback about design-related issues. Once again, collaboration between team members can increase a project's sustainability by reducing the amount of time needed for documentation and working with a more accurate cost estimate and schedule (AIA National & AIA California Council, 2007).

Additionally, the group effort of the constructor and designer could lead to fewer on-site errors, requests for information, change orders, and less wasted time spent on communication. In fact, it has been calculated that the project manager can spend 75-90% of their time communicating (Guggemos & Glick, 2009). Clearly, there are numerous benefits to including both the constructor and designer early in the project.

Another IPD principle, *Appropriate Technology*, goes hand in hand with collaboration and integrated design. Building Information Modeling (BIM) has the ability to save more time, money, and materials by promoting interoperability of project drawings, cost estimates, and schedules among project team members. There have been several case studies that report the success of BIM. Chris Leary, AIA, of KlingStubbins, states, "The integrated process and the support of BIM has been a boon for green objectives. On LEED projects...there is often an assumption in the process that you'll do

conventional [construction], and anything green is treated as an option.” Now, he says, “We’re starting to do a lot more things with more confidence because we can prove with the digital model that they can work. These alternatives become embodied in the project much sooner.” (Roberts, 2008). Roberts’s (2008) series of case studies on using IPD and BIM shows proof that the two can lead to greater efficiencies, sustainability objectives, and improve the performance of a building.

The structural steel industry has already begun to incorporate the principles of Integrated Project Delivery into their delivery methods. The industry is moving toward integrated design practices and utilizing BIM, which should make incorporating IPD, and thus seeing the benefits of IPD, a smooth transition. IPD can green the structural steel industry through early involvement of project team members, working towards collaborative communication, spending more time and effort during the critical design phases, and utilizing BIM, which ultimately leads to a higher quality product with less waste and more “green” outcomes.

## **Chapter 3: Methodology**

### **3.1 Introduction**

Research data is collected using quantitative and/or qualitative research techniques. Quantitative research focuses heavily on numerical data, measuring the performance of individuals and establishments among two or more topics. Research questions are very specific and are supported by a hypothesis. Data is collected from a large number of participants with a number of tools, such as experiments and surveys. Once the data has been collected, it is analyzed and converted into scores and/or statistics, if relevant. The results are then compared with the hypothesis as well as past studies in order to draw associations that support the study's purpose. A quantitative researcher will practice an objective and unbiased approach during data collection and analysis (Creswell, 2008).

Qualitative research, on the other hand, is a type of research that sets out to answer a set of broad and universal questions with textual or graphic data rather than numerical data (Miles & Huberman, 1984). Qualitative research is used most often when a central phenomenon requires further exploration than what is present in existing literature. A qualitative researcher will build upon the views and experiences of a smaller number of participants in order to answer research questions. It is common to collect data through interviews and observations at a participant's place of work or home. A qualitative researcher will ask a series of broad questions, listen as participants speak

about their experiences, and then analyze the results to further understand the central phenomenon at hand. The researcher will seek out common subject matter within the data in order to draw out larger meanings to answer the research questions. A qualitative researcher will practice a subjective and biased approach during data collection and analysis (Creswell, 2008).

Often, a study will include both quantitative and qualitative methods to answer research questions. This study, however, used a qualitative approach to determine the value of including secondary stakeholders in the delivery method of structural steel for the National Renewable Energy Laboratory (NREL) Research Support Facilities project. Qualitative research was most appropriate for this study as there was a central phenomenon, the delivery method for the NREL building, which required a deeper understanding due to the limited amount of literature on the topic. The researcher used a case study, the NREL project, to evaluate the delivery method of structural steel. Since the researcher only focused on one case study, no large generalizations should be drawn from the results of this report.

The researcher based the study on a Grounded Theory Design as a means to collect, evaluate and report data. Grounded Theory Design is best suited for research that involves studying numerous individuals who have experienced similar interactions and procedures, such as the delivery method of a building (Creswell, 2008). The researcher developed a general explanation, or grounded theory, for the delivery method, level and frequency of communication among team members, level of involvement, and types and amount of inefficiencies and opportunities for the NREL project. Data was collected through one-on-one interviews followed by a focus group session. The researcher

analyzed, transcribed, coded, and then reported the findings of this study.

### 3.2 Population

Participants were chosen as part of a purposeful sampling to ensure that the key population understood the delivery method for the NREL building, or central phenomenon. Purposeful sampling required that the researcher understand the larger issues at hand, i.e. traditional delivery methods and Integrated Project Delivery (Creswell, 2008). Therefore, the researcher conducted a thorough literature review to understand these greater topics. The researcher determined specific participants in partnership with thesis committee members. Table 2 lists the interview participants.

**Table 2. Interview participants from the NREL Research Facilities Project team**

<b>Interview Participant</b>	<b>Company</b>	<b>Field of Services</b>
Project Manager	RNL	Architecture
Project Manager	Haselden Construction, LLC	Construction
Senior Superintendent	Haselden Construction, LLC	Construction
Project Manager	LPR Construction	Erection
Site Superintendent	LPR Construction	Erection
Chief Engineer	Paxton & Vierling Steel (PVS)	Fabrication
Project Manager	Paxton & Vierling Steel (PVS)	Fabrication
Principal	MKK Consulting Engineers, Inc.	Owner Representation
Detailing Manager	KL&A, Inc.	Structural Engineering
Principal Engineer	KL&A, Inc.	Structural Engineering
Engineering Manager	KL&A, Inc.	Structural Engineering
Structural Project Manager	KL&A, Inc.	Structural Engineering

These participants were best suited to provide useful information in order to answer the research questions and fulfill the purpose of this study. Additional participants

were not necessary, as each participant represented the information needed by that particular profession. One-on-one interviews occurred in a place of mutual agreement between the researcher and participant. The focus group interview took place at the NREL project site in Golden, CO.

### **3.3 Obtaining Interviews**

In order to contact the participants, the researcher emailed each individual. The researcher began each email by explaining the research situation, purpose and goals of the study, and any progress to date. The second part of the email explained the purpose, length, possible dates and locations of the interview. Finally, the researcher explained how the results of the interviews would be reported and disseminated (see Appendix I).

### **3.4 Method of Data Collection**

The primary method of data collection was via interviews. Interviews were the best tool for this study because they allowed the researcher to gather information that previously happened during the design, fabrication, and erection phase of the NREL building. The researcher asked broad, open-ended questions so that participants could answer without being persuaded by the interviewer (Creswell, 2008). The interview questions were pre-written in a certain order, but ultimately, the interviews were unstructured, and the participants had the freedom to steer the interview relatively unconstrained. Probing questions were also developed for each topic question in order to help the participant narrow the focus of their answer or clarify information (see Appendix II). If the conversation strayed from the topics of the study, the interviewer guided the participant back to the questions at hand (Weiss, 1994).

The researcher conducted one-on-one interviews followed by a focus group session with all participants. One-on-one interviews were best suited for the first round of interviews, as the researcher created a safe environment in which each participant was free to speak about other project team members or sensitive issues without being influenced, intimidated, or disrupted by other participants (Weiss, 1994). If any participants were unable to meet in person for an interview, they participated via conference call.

Following all one-on-one interviews, the researcher held a focus group session with all participants. A focus group session was appropriate because participants had the opportunity to communicate with each other in order to yield the most practical information for process improvements (Denzin, 1989). Furthermore, all participants were on the same project team and had already developed a working relationship with each other, which helped to create a supportive environment (Creswell, 2008). The researcher interviewed participants on the feasibility of suggested opportunities for improvement based on the results of the one-on-one interviews (see Appendix IV). If any participants were unable to attend the focus group session in person, they participated via conference call.

In order to document the interviews, the researcher audio taped the one-on-one interviews and audio taped and videotaped the focus group session. This allowed the researcher to focus solely on the participant(s) while taking occasional notes as backup (Weiss, 1994). Before each interview began, the researcher asked the participant(s) for permission to record the interview. All participants allowed their interview to be recorded. In order to create a trusting and comfortable environment, the researcher

explained to each participant that the information discussed would only be used for the purposes of this study (Weiss, 1994). Participants were required to sign a consent form before the interview began.

During the one-on-one interviews, the researcher focused on listening to the participant, ensuring that the questions were eventually answered. The researcher abstained from declaring any personal views on the topic at hand. Each interview lasted approximately 45-70 minutes. Once the interview was complete, the researcher thanked the participant and informed them that a summary of the interview would be available for them to review to ensure accuracy (see Appendix III).

Once all one-on-one interviews were complete and each participant had determined their interview summary as accurate, the researcher held a focus group session with all participants. In order to prepare for the focus group session, the researcher compiled a list of the suggested scenarios from the one-on-one interviews. During the focus group session, the researcher presented each suggested scenario to the team (see Appendix IV). The researcher focused on listening to the participants and ensured that each scenario was addressed. The researcher abstained from declaring any personal views on the topic at hand. The focus group session lasted two hours. Once the session was complete, the researcher thanked the participants and informed them that a draft report would be available for their review.

### **3.5 Treatment of Data and Analysis**

After all interviews were complete, the researcher began to analyze the data. The first step was to upload all data into *NVivo*, a qualitative data computer program. *NVivo* allowed the researcher to organize the data, such as text and video and audio data files,

into one location. Once the interview data has been uploaded, the researcher listened to each interview, took copious notes, divided the data into segments, and labeled each segment with various titles, such as “communication” or “construction issue.” The researcher then read through the titled segments to search for emerging themes, which formed the key ideas of the findings (Miles & Huberman, 1984) (See Appendix V and Appendix VI).

Once the data has been grouped into themes, the researcher transcribed portions of the individual interviews and focus group session that were relevant to the themes. The researcher then reported the findings as narrative discussions and visual findings such as charts and graphs. The narrative discussion supported the themes by incorporating direct quotes that expressed the varying perspectives and observations of participants. In order to ensure that the data was truthful, the researcher sent the findings to each participant to review for accuracy (see Appendix V and Appendix VI).

## **Chapter 4: Findings**

The two research goals for this study were to (1) determine the opportunities and efficiencies that exist as a result of using Integrated Project Delivery (IPD) versus a traditional delivery method for the National Renewable Energy Laboratory (NREL) Research Facilities (RSF) project and (2) determine the benefits of including secondary stakeholders in the design phase of structural steel for the NREL RSF project.

In order to accomplish the research goals, two types of interviews were conducted. Individual interviews were conducted first, followed by a focus group interview, or session. Based on the outcomes of the individual interviews and focus group session, the researcher identified several opportunities for improvement and process recommendations. The opportunities for improvements and process recommendations outlined in this chapter are based on the notion that inefficiencies result in increased physical waste, which negatively impact sustainability efforts. The underlying assumption is that by increasing efficiencies throughout the structural steel delivery process not only are costs reduced but waste, time, energy, materials, and the overall environmental impact of the structural steel industry is lessened.

Several of the opportunities for improvement and process recommendations listed in this chapter address the second research goal. More specifically, sections 4.1.1.1.4, 4.1.1.3.1 – 4.1.1.3.6, 4.1.1.6.1, 4.2.2 address the benefits of including secondary stakeholders in the design phase of structural steel. The first research question for this study, however, was not able to be answered. Participants revealed several facts that

countered the use of IPD during the individual interviews. The researcher addresses this topic in detail in section 5.2.

It is important to note that there are several opportunities for improvement that do not address either of the two research questions. These findings are still important to consider, however, because (1) they were mentioned during the individual interviews and (2) they are relevant opportunities for the structural steel industry to consider in an effort to lessen their environmental impact.

#### **4.1 Individual Interviews**

Several NREL project team members were interviewed individually (see Table 4) to determine the level of integration of the steel stakeholders used on the project and allow for participants to discuss any inefficiencies and/or opportunities for improvement based on their experiences. During the eight individual interviews, participants revealed a total of thirty opportunities for improvement that may reduce the environmental impacts of the structural steel delivery process. The suggestions were grouped into themes and the incidence of each reported suggestion was noted (See Table 3). The themes are ranked by frequency of occurrence.

**Table 3. Number of opportunities for improvement by theme.**

<b>Theme</b>	<b>Number of Suggestions</b>
Construction Issues	8
Communication	7
Early Involvement	6

Technology	3
Applying Lessons Learned	2
Implications of Steel Delivery Method	2
Transportation of Steel	1
Mechanical Systems	1

Within each of those eight themes, there are several opportunities for improvement for the delivery of structural steel. Each theme is presented as a synopsis of the issues discussed in the individual interviews. Each description will include background information, the issue at hand, and possible solutions. Interview participants are referred to by the title of their profession to retain confidentiality. As a reference, Table 4 lists participants, their associated company, and the company’s field of services.

**4. Individual interview participants, associated companies, and fields of service.**

<b>Individual Interview Participant</b>	<b>Company</b>	<b>Field of Services</b>
Project Manager	RNL	Architecture
Project Manager	Haselden Construction, LLC	Construction
Project Manager	LPR Construction	Erection
Site Superintendent	LPR Construction	Erection
Chief Engineer	Paxton & Vierling Steel (PVS)	Fabrication
Principal	MKK Consulting Engineers, Inc.	Owner Representation
Detailing Manager	KL&A, Inc.	Structural Engineering
Structural Project Manager	KL&A, Inc.	Structural Engineering

#### **4.1.1 Opportunities for improvement.**

The following themes and opportunities for improvement represent issues that were discussed during the individual interviews that are relevant to the delivery of structural steel.

##### ***4.1.1.1 Construction issues.***

During the interviews, participants mentioned several issues that directly related to the construction process for the NREL RSF project. This theme was mentioned the most during the interviews. There are eight opportunities for improvement.

###### ***4.1.1.1.1 Cranes to be handled by the erection team.***

According to the Project Manager with LPR, the erection team brings the crane equipment to the project about 75% of the time and it is their instrument. An appropriately sized crane should be able to reach steel members within a certain circumference and lift a certain amount of weight. Therefore, a crane is considered too small when a piece of steel cannot be picked up and placed where it needs to go by the arm of the crane, or the weight of the steel member exceeds the crane's capacity. On this particular job, Haselden Construction procured the cranes rather than LPR Construction (LPR). The size of the crane that was ordered presented a problem for LPR during erection.

Part way through the job there was a change in the size of a truss member. Due to the increased member size, the cranes that were on the job site were now too small to erect the larger truss. The immediate solution was for Haselden Construction to procure a bigger crane. However, this was inefficient for LPR, as there were cranes moving in and out of the already constrained job site. Switching the cranes affected erection and changed the flow of work for LPR. It was a disruptive element to the process and LPR had to plan around it. According to the Project Manager with LPR, LPR suffered at least

a one week delay because of the issue, although they still adhered to the construction schedule. The Project Manager with LPR Construction stated, “We tried to have a discussion with Haselden Construction early on about “cranage” and make sure we were all on the same page. It didn't seem to bear any fruit.” Haselden Construction still gave LPR a different crane than they requested.

A few possible solutions if acted upon might have changed the situation. First, the issue might have been avoided if the crane was sized according to LPR's request. Secondly, this issue may have been avoided if LPR was in charge of procuring the cranes. LPR Construction's Project Manager shared that LPR would have ordered a bigger crane from the beginning. The crane provided by Haselden Construction was already almost too small even before the size of the truss girders was changed. Lastly, the Project Manager with LPR Construction suggested that a tower crane might have been a better choice. The team may have been able to place the tower crane in one place on the site and erect the entire job from that point. The Project Manager with LPR Construction also pointed out that a tower crane would also require a sizeable foundation to support it.

#### *4.1.1.1.2 Increased site access.*

The construction site for the NREL RSF project was somewhat landlocked and the erection crew had access mostly on the east side of the site. To one side, there was a narrow strip of ground on the roadway that was hardly passable for large equipment, such as a crane. The H-shape of the NREL RSF building and the constrained site made it difficult for LPR to move the erection cranes around the building. It was necessary to move the crane around the building in order to erect all steel members. Once the crane moved to one side of the building, it was then difficult to move materials to the other

side. The Project Manager with LPR Construction shared, “When we started on the west end, we were essentially trapped over there, and you couldn't go and unload materials on the east end very easily.” The mobility constraints for large equipment on the site created extra work for LPR, which took more time. Furthermore, the Superintendent with LPR Construction expressed a concern for site safety, as the erection crew was working at a quicker pace in order to meet the construction schedule.

An opportunity for improvement would be to allow for more than one point of access and/or increase storage capacity on site so that the erection crew may work as efficiently as possible. Another solution suggested by the Superintendent with LPR Construction was to slow down the construction schedule so that contractors were not working on the same enclosed job site at one time. The Superintendent with LPR Construction stated, “You know, everybody's trying to work on top of each other. That's not really productive for anybody.”

#### *4.1.1.1.3 Have power to the site before construction begins.*

During erection there was not enough electric power provided on site to complete welding and power a stud machine without the aid of a generator. LPR had to bring in a 250kW generator, which had about an 8” exhaust pipe and a 400-gallon diesel tank to weld nelson studs in the field. This created a lot of noise and exhaust. The Project Manager with LPR Construction revealed, “Every time you pulled the trigger on that gun a huge cloud of smoke would belch out into the air.” In fact, it has been calculated that powering the erection phase with electricity, rather than using diesel welders, would reduce the amount of CO<sub>2</sub> from erection activities by 1.7%. Furthermore, removing diesel generators from the erection process would reduce the amount of particulate matter

released into the air by 6.7%, which increases air quality on site (Guggemos, Plaut, Bergstrom, Gotthelf, Haney, et al., 2010).

In order to avoid having to use a diesel generator, the electric power would have had to be connected to the site before construction began. The Superintendent with LPR Construction simply stated, “The biggest thing on our parts is power on the jobs. Get power on the jobs sooner.” The Project Manager with LPR Construction further suggested considering increasing section sizes instead of installing shear studs. This could have avoided the need for a generator.

#### *4.1.1.1.4 Weld the deck to steel instead of fastening the deck to concrete.*

The crawl space for the NREL RSF structure is made entirely of concrete. In order to fasten the deck to the crawl space, the Superintendent with LPR Construction had to use Hilti pins to create a solid connection. The decision to fasten the deck to the concrete crawl space was made by KL&A. This caused several problems for LPR though. In order to shoot the Hilti pins the team had to use a powder-actuated gun that would sometimes damage the concrete due to the force. The damaged concrete might chip or break off surrounding the connection point. LPR would then have to take the time to fix the damaged concrete to secure the fasteners. Furthermore, the space surrounding the fastened pins would sometimes become loose due to changing weather. The Superintendent with LPR Construction stated, “You come back two days later after Colorado winters and Colorado nights and expansion and compression pops all those pins loose.” Some days, the erection crew would shoot in the Hilti pins, come to the site the next day, and have to redo them because they were loose.

The Superintendent with LPR Construction suggested that a possible solution to this problem would be to use steel as well as concrete in the crawl space. LPR could then weld the deck to steel for a more secure and reliable connection. LPR Construction's Superintendent estimated that fastening the deck to concrete probably took about 30-40% more time than if LPR would have been able to weld the deck to steel. This problem might have also been avoided if a member of the erection crew had been involved in the design of the crawl space and deck connections. The Superintendent with LPR Construction shared that he would have influenced that decision if he were involved in the design phase. The erection team has vast experience with different types of connections and welding types. Perhaps LPR could have pointed out this issue if they were involved in the design phase.

*4.1.1.1.5 Use wedge anchors for deck support instead of epoxy anchor bolts.*

The Superintendent with LPR Construction pointed out that the deck support angle going into the crawl space was a problem. Instead of using wedge anchors for the deck support angles, LPR was instructed to use epoxy anchor bolts. However, the epoxy anchor bolts took twenty-four hours to cure. As a result, LPR would put two wedge anchors in, hang the deck support angle, and then wait twenty-four hours to return and tighten up the nuts for each particular anchor.

The Superintendent with LPR Construction stated that it is more efficient for the erection team to use wedge anchors, as the epoxy anchor bolts take more time to install. The Superintendent with LPR Construction estimated, "It's another probably 50% savings if they went with wedge anchors."

#### *4.1.1.1.6 Use of steel stair cores rather than concrete stair cores.*

The Superintendent with LPR Construction expressed that it is quicker and cleaner for the erectors to work with steel stair cores rather than concrete stair cores. Part of this ease is due to the fact that there are never any connections to embeds with steel stair cores. This project did have a few misplaced embeds, which caused slight delays for LPR. The Superintendent with LPR Construction explained that by using steel stair cores the erection team would simply come in once the stairs were connected and place studs around it for stability.

#### *4.1.1.1.7 Increase coordination for steel and concrete components.*

The coordination between steel and concrete was a struggle on this job. The Detailing Manager with KL&A revealed that the problem was misplaced embeds, which caused delays in schedule and resources because the steel could not be erected. Apparently, Haselden Construction identified some inefficiencies in their system that may have contributed to the misplaced embeds.

KL&A's Detailing Manager suggested that perhaps the problem could have been lessened by providing the construction crew with different types of drawings that outline the necessary information clearer. At the time of the interview, the design and steel team were researching different ways to improve the process. The Detailing Manager with KL&A felt that more upfront planning and coordination might result in fewer complications in the field. The Detailing Manager with KL&A stated, "When we're looking at more ways to make that more efficient, you know what we can do as the design and steel team to make that happen better? Better communication, you can always communicate better."

#### *4.1.1.1.8 Increased quality control.*

The Superintendent with LPR Construction discussed several miscellaneous errors that, in his opinion, showed a lack of quality control. For example, there were misplaced embeds, a few steel fabrication errors, field connection problems, and design issues with bent plates. All of these issues slowed down LPR's flow of work. For example, the Superintendent with LPR Construction estimated that one misplaced embed could slow the erection process down one week to ten days. This lag time is dependent on the magnitude of the problem and how quickly the problem can be fixed. In the meantime, LPR is forced to work around the issue and come back to it at a later time.

Perhaps some of these field errors could have been avoided by increasing the overall quality control effort. The Superintendent with LPR Construction stated that even though there were quality control measures in place, items were still overlooked.

#### *4.1.1.2 Communication.*

The second most commonly mentioned theme during the individual interviews was communication. During the interviews, the researcher questioned participants about the structure of communication within the project team and the level and frequency of communication among project team members concerning the structural steel delivery. The following section elaborates on the seven opportunities for improvement relevant to communication.

##### *4.1.1.2.1 Allow the steel detailing team and structural engineering team to communicate openly throughout the entire project.*

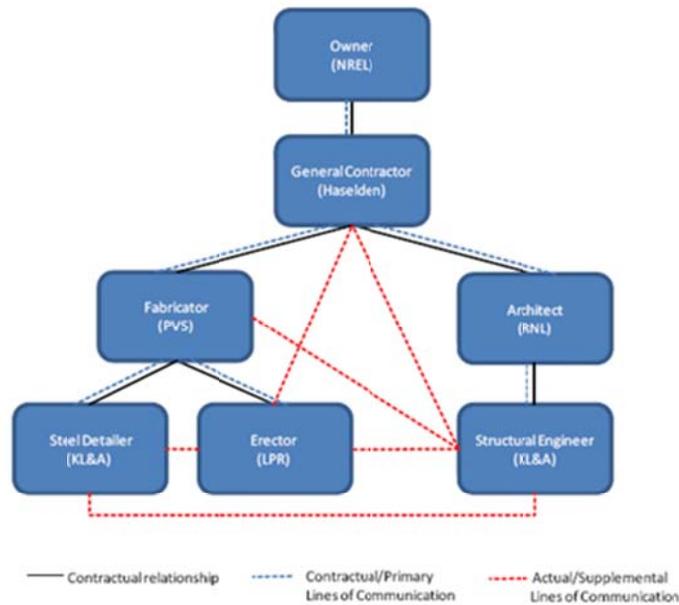
The Detailing Manager with KL&A was able to talk directly with the Structural Project Manager with KL&A only during shop drawing production as opposed to having

open communication during the entire project. If a problem was identified, the Detailing Manager with KL&A could call the Structural Project Manager with KL&A on the phone and resolve the issue immediately rather than going through the process of writing a Request for Information (RFI) first. The steel detailing team did not have many RFIs for this project, however, because of the open lines of communication during shop drawing production. The open lines of communication between the Detailing Manager with KL&A and the Structural Project Manager with KL&A also resulted in less rework.

On other phases of the project, however, a more traditional approach was taken to communicate and resolve issues, especially if the issue affected the schedule or budget. In this instance, someone would write a RFI, send it to the appropriate project team member, and wait anywhere from three days to one week to one month, for a response. The Detailing Manager with KL&A stated that it is not uncommon to wait one week for a response.

#### *4.1.1.2.2 Establish a contractual line of communication between the steel detailing team and the erection team.*

According to contractual agreements for the NREL RSF project, the steel detailing team was required to go through PVS if there was a need to contact LPR (see Figure 6).



**Figure 6. Contractual arrangement for the structural steel delivery of the NREL project.**

However, the Detailing Manager with KL&A revealed in the interview that she spoke with LPR quite a bit at the beginning of the project and bypassed PVS. The Detailing Manager with KL&A was often working on components that would directly impact the erection crew. Thus, the Detailing Manager with KL&A called LPR quite a few times to get direct feedback on erection details.

The fact that the Detailing Manager with KL&A was able to resolve issues quicker by going outside of the contract rather than following the traditional lines of communication speaks to the inefficiency of the communication hierarchy for the NREL RSF project. This issue could have been resolved by allowing direct lines of communication between the steel detailing team and erection team. The Detailing Manager with KL&A stated, “The erector would be somebody that I would always like to have a direct line of communication with.”

*4.1.1.2.3 Direct lines of communication between the fabrication, erection, steel detailing, and structural engineering team.*

If there was a fabrication, erection, or detailing issue on this project the structural engineering team would have to go through the architecture team, the architecture team would communicate with the contractors, the contractors would get in touch with PVS or LPR, and then they would get in touch with the steel detailing team (see Figure 6). To complicate matters even further, the steel detailing and structural engineering team were both with KL&A, but they were hired by separate entities at different times. The Structural Project Manager with KL&A revealed that there was some direct communication for quick questions, but anything of substance would have to go through a long loop of communication. This system of communication between the engineering, fabrication, structural engineering, and steel detailing team would take anywhere from two days to two weeks.

KL&A's Structural Project Manager suggested that these issues would have been resolved quicker if the structural engineer would have been able to communicate directly with the fabrication, erection, and steel detailing team. The Structural Project Manager with KL&A also shared, "You can deliver a project much faster because if you're both designing and detailing the job, then you can start your detailing model and detailing much sooner in the process." KL&A would have preferred to hire the fabricator, erector, and steel detailer, thus having a direct contract with them as well as having more control over response time. The Structural Project Manager with KL&A stated, "It's very nice to have the fabricator and erector at your disposal for questions or comments especially during construction. You spend less time going through the loops of communication to make sure everybody's involved with everything."

The Structural Project Manager with KL&A spoke about a particular issue that involved the fabrication team. PVS provided an initial price for the girder connections and then a final price after construction documents were complete. The initial price was based on the set of plans that were provided to PVS. Haselden Construction periodically sent PVS updated plans so they could follow design changes and alter pricing and fabrication plans if needed. However, when PVS gave their final price sometime later, the girder connections had changed and PVS was unaware of the changes. They requested an add-service for their final estimate since the connections were not what they thought they were going to be. KL&A's Structural Project Manager revealed that there was a long window between the initial price and the final price, in which there should have been a couple price updates. The prices were eventually resolved, but it was not until after construction had already begun. The Structural Project Manager with KL&A stated, "There was some resolution, but it was once we were into the construction phase where things are not as easily changed." Changes during the construction phase can often be more expensive and time consuming (AIA National & AIA California Council, 2007). PVS had to complete some rework because of the girder connection changes, and there were also delays in the first sequence of fabrication as a result. The Structural Project Manager with KL&A estimated that it took about three weeks to one month to resolve.

This issue may have been avoided if KL&A would have been able to directly communicate with the fabrication team. KL&A's Structural Project Manager shared that new plans were being sent at frequent intervals and KL&A could have made sure that PVS was kept in the loop.

#### *4.1.1.2.4 Equal interaction among the owner's representation team and the design team.*

On most private projects, the owner has a large amount of influence and voice in the design of a building. MKK Consulting Engineers's (MKK) contract for this project was with the federal government, and therefore a public project. The contract required that MKK review the design documents to make sure they fulfilled the Request for Proposal (RFP). MKK was not allowed to influence any design decisions; rather they could only check for verification of the RFP.

The Principal with MKK Consulting Engineers felt that this arrangement was problematic. MKK was restricted from collaborating on the very design decisions that they were crosschecking. The Principal with MKK Consulting Engineers felt that this hindered the ability for the NREL RSF project to be an integrated design project. The Principal with MKK Consulting Engineers stated, "They [the design team] designed, we reviewed, we input, they changed, we reviewed and input. So it was kind of jerky. It wasn't as fluid as I thought integrated design could be." The Principal with MKK Consulting Engineers also pointed out that even though some design decisions may have met the RFP, it did not mean that they were the best sustainable options.

#### *4.1.1.2.5 Increased understanding of the gas pipe columns.*

The NREL RSF Project incorporated a unique architectural and structural element by utilizing reused gas pipe columns for structural columns. A recent study quantified the environmental impacts of this element and found that reusing the gas pipe columns reduced more than 69% of the energy that would have been required to produce new comparable materials (Guggemos, Plaut, Bergstrom, Gotthelf, Haney, et al., 2010).

In order to strengthen the columns and properly support the building structure, the recycled gas pipe columns required concrete to be poured in the lower segment of the column. This created a disruption in LPR's flow of work that is not typical to most steel erection jobs. The Project Manager with LPR Construction revealed that the purpose of the concrete was unclear to his team. The Project Manager with LPR Construction stated, "I don't have the insight into what the design philosophy was that required the concrete. I've speculated a couple things."

Perhaps this confusion could have been avoided if KL&A communicated more with team members about the unique design and impacts of using round pipe columns.

#### *4.1.1.2.6 Earlier communication between the structural steel team members.*

This project presented some complicated connections due to the steel framing situation. The NREL RSF structure had some high transfer loads and joists that were sometimes framing in or sitting on round columns.

KL&A identified some erectability and fabrication issues on one of the design sets, particularly the connections between the joists and the round columns. The connection issue was resolved by bringing project team members together and brainstorming solutions. Fortunately, this issue was resolved before construction began.

This issue required coordination between the fabrication team, the joist manufacturers, the engineer of record, the steel detailing team, and the erection team. The Detailing Manager with KL&A stated, "Moving on to the next entire project, we always say we need to communicate more up front." A delay in the design set might have been avoided if the project team had discussed the joist and round column connections earlier.

#### 4.1.1.2.7 Earlier coordination and approval of section F of the RSF project.

An additional wing on the RSF project, section F, was approved late in the design phase (see Figure 7). This decision put a hold on the fabrication that was taking place for section E. PVS received a revised set of connections for the columns that would be sheared by both structures (sections E + F), which included a new type of connection. PVS had already fabricated the majority of steel for section E however, by the time the new wing was approved. The Chief Engineer with PVS stated, “We were probably 95% through the structure when they finally made the actual decision to add that last wing on.” Nonetheless, PVS fabricated and shipped the new connections to the site. This was the only time PVS had to send a partial truck load to the site (5 tons on a 20 ton capacity truck). According to the Chief Engineer with PVS, the architectural and structural engineering teams for the project were brainstorming ways to use the extra fabricated steel from section E in the new wing.

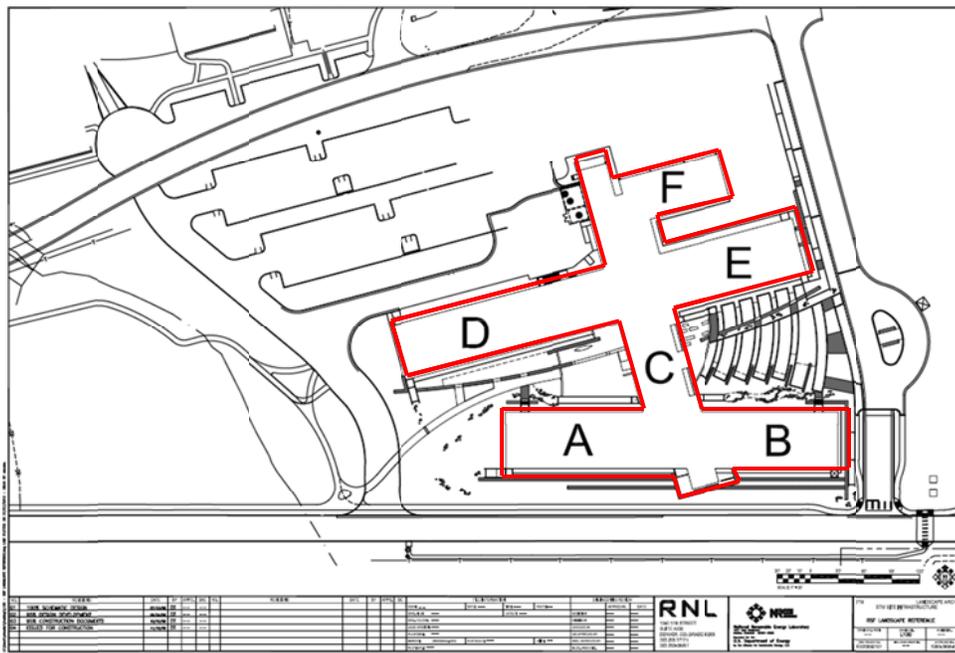


Figure 7. National Renewable Energy Laboratory Research Facilities Project site infrastructure plan illustrating the order of sequencing. Adapted from an image courtesy of RNL.

PVS's Chief Engineer shared that this issue might have been avoided if section F was approved earlier in the project. This would require earlier coordination and communication.

#### ***4.1.1.3 Early involvement.***

Another prominent theme from the individual interviews was early involvement. The interview questions were directed at gaining insight on the value of including the fabricators and erectors early on in a project. However, results show that not only do participants agree that the fabrication team and erection team should be involved during the design phase of a project, but that all stakeholders should be contributing their input at the beginnings stages of a project. More specifically, participants suggested involving the contractors, fabricators, structural engineering team, erectors, product manufacturers, and steel detailing team early on in the project. The following six opportunities for improvement represent the relevant interview discussions.

##### ***4.1.1.3.1 Work through potential issues early on in design.***

Early involvement between the contractors, fabricators, and structural engineers can lead to more coordination early on, the opportunity to ask more questions at the beginning of a project, and catching potential issues. Although the Design-Build nature of this project allowed for some open lines of communication, it took team members a while to accept and understand the idea of an integrated project team. Some team members were used to designing and constructing a project in a more traditional delivery method, and it took a while to shift towards open and integrated communication. Haselden Construction's Project Manager shared:

It's cliché, but that paradigm shift of doing an integrated project team just took a while to understand. All members were enthusiastic and wanted to embrace that

as much as they could, but then you have decades of experience doing it a different way and people just didn't realize some of the opportunities we might have had as early as we wish we could have.

More specifically, Haselden Construction's Project Manager would have liked to see more communication between the engineer and fabricator early on, as they have much influence over each other.

This issue became apparent to the Project Manager with Haselden Construction because of some extra coordination that was needed to clarify a detailed moment connection between the round columns and the joists. The structural engineering team originally designed the connection, but the project team was able to find a more efficient means of connection using the fabricator's ideas. The fabrication team and structural engineering team worked together, and as a result, they were able to save some field welding time. Haselden Construction's Project Manager was involved in the discussion as a moderator. Haselden Construction's Project Manager estimated that this issue took about two weeks to resolve but did not impact the construction schedule.

#### *4.1.1.3.2 Utilize the fabricator's perspective.*

The exposed joists for the RSF project had to be a certain depth in order to allow optimal daylighting inside the structure. The engineering team, architecture team, and preconstruction department worked together on this particular issue. Originally, the architecture team determined the necessary depth of the joists according to the lighting consultant. However, the steel structural members were not yet planned when the joist depth was determined; therefore, certain loads were assumed during design. The Project Manager with Haselden Construction shared, "The general assumption was this joist will carry the sufficient load. Then we realized that specific joist doesn't work." This was not

a significant issue, as there was no change order submitted and the team was able to work through it. Haselden Construction's Project Manager felt that had the fabricators been involved during the design of the building, they might have been able to foresee a potential conflict between the building design and the structural steel frame.

#### *4.1.1.3.3 Consult the erection team for sequencing decisions.*

LPR Construction's Project Manager felt that the planned flow, or sequencing, of construction did not take into account site constraints. This created some challenges relative to moving large pieces of equipment and receiving deliveries of materials.

This issue might have been avoided if the erectors were able to have input on the sequencing of this project. The Project Manager with LPR Construction believes erection would have gone smoother if the A, C, and D wings were completed first rather than A, B, and then C (see Figure 7). The Project Manager with LPR Construction states, "If you wanted to optimize the job from our perspective, that's what we would have done." If the building was constructed in that order, the crane would have been able to move to the other side of the structure to complete the B, C, and E wings. The Project Manager with LPR Construction believes this might have required fewer and/or smaller cranes and required less time to complete erection. Furthermore, if LPR was included in the early design decisions, they might have been able to point out potential erection issues due to the shape of the building and site constraints.

#### *4.1.1.3.4 Take advantage of each stakeholder's diverse knowledge.*

PVS was brought onto the project after all the structural steel connections were determined. PVS reviewed the moment connections for the joist girders to the reclaimed columns in order to develop an estimate for labor costs. PVS's labor calculation was

more expensive than what had been anticipated by the project team. KL&A asked PVS to think of some alternatives for the connections in order to bring the labor cost down. PVS worked with the engineering team to develop a new connection that ended up saving time and money. This whole process took about two weeks to resolve before KL&A accepted the new connection and associated labor cost.

This issue might have been avoided if the fabricators and steel detailing team were brought onto the design team earlier. The Chief Engineer with PVS stated, “I think it is always good practice to bring the fabricator and the detailer onto the design team long before the design documents are finished.” PVS’s Chief Engineer also shared that the fabricators and steel detailers are able to view building plans from a different perspective than an engineer or architect, and thus can add valuable insight to the design of the connections.

#### *4.1.1.3.5 Address architectural and structural concerns simultaneously.*

The floor-to-floor height was reduced by 6 inches part way through design due to budgetary constraints. With the raised floor ventilation system and a shrinking floor-to-floor height, issues arose when the exposed steel trusses began to interfere with the daylighting.

Despite the floor-to-floor height reduction, the truss girders still needed to be 48 inches deep for structural purposes. The Project Manager with RNL was also concerned that the deep truss girders would create the illusion that the floor to floor height was restrictive and make the space feel too small for the building occupants. At the point at which the floor-to-floor height was cut, the Project Manager with RNL expressed that there was never a window of time to slow down and revisit the truss design. Shop

drawings were already complete and the construction schedule was far beyond being able to re-examine the truss design. Any suggestions or changes most likely would have increased costs. The Project Manager with RNL stated, “That was a bit of a challenge for the project from the design side because that piece of the thing didn't really get designed until we were all ready to put it up.” The issue did not take much time to resolve, as it was just a matter of the architecture team accepting that the truss depth had to be at 48 inches. RNL never contacted the fabricators about the issue because they felt it was not practical to do so. RNL’s Project Manager expressed that it was more of an aesthetic concern rather than a concern over the structural integrity of the building.

RNL’s Project Manager suggested that this conflict might have been avoided, however, if there were discussions during the early design phase, perhaps right after conceptual design, about the design of the girders. The structural engineers could have shared the requirements for the girder size and shape, and the architects could have designed accordingly. The fabricators would have needed to be involved as well, since they would be the ones actually making the steel components. Perhaps the structural engineering team and fabricators could have offered insight about the potential conflicts between the design and structural frame of the project. The Project Manager with RNL also suggested that KL&A could have designed a custom truss girder that would appease the aesthetic and structural needs.

#### *4.1.1.3.6 Obtain manufacturer feedback.*

The Principal with MKK Consulting Engineers explained that on most projects when the decision is made to include a particular product in a project a contractor must contact the manufacturer to find out how long production and delivery will take before it

can be delivered to the site. If a contractor does not contact the manufacturer about production and delivery early on there may be problems during application in the field.

The Principal with MKK Consulting Engineers expressed a concern that there were not any manufacturers sitting around the table during the design phase. The Principal with MKK Consulting Engineers stated, “If you were going to have it [the design] totally integrated, I would say you get the manufacturers or the reps involved at the table also.” The manufacturers should be involved at that early stage in order to provide information about their products. This might, after all, influence certain design decisions. The Principal with MKK Consulting Engineers believes it is better to find out information about products during design rather than during application in the field.

#### ***4.1.1.4 Technology.***

There were some concerns expressed during the individual interviews about the use of appropriate technologies for the NREL RSF project. The following three opportunities for improvement were discussed.

##### *4.1.1.4.1 Utilize electronic documents.*

KL&A did their best to eliminate paper trails on this project by submitting and reviewing as many documents as possible electronically. The Detailing Manager with KL&A explained that KL&A used to produce five to six sets of drawings for their review process. The steel detailers would send the drawings to the fabrication team, the fabrication team would make copies, and then ship them all to the construction team. The construction team would then ship the drawings to the architectural team, the architectural team would ship them to the structural engineers, and the structural engineers would send them back to the architectural team. The architectural team would

then send them to the construction team, the construction team would ship them to the fabricators, and they would then end up back on the steel detailer's desk.

To avoid the use of paper and associated transportation costs, all submittals were done electronically to PVS. The only time something would get printed is if a hard copy was needed. A lot of reviews were done electronically as well. The Detailing Manager with KL&A stated that KL&A had some paper trail but not as much as if they had distributed hard copies of the drawing sets. The Detailing Manager with KL&A believes a smaller paper trail also allowed for savings on fuel and shipping costs.

While KL&A's effort is commendable, utilizing electronic documents was not a team-wide initiative for this project. It is unclear how many hard copies other project team members printed out at the tail end of a submittal.

#### *4.1.1.4.2 Utilize more appropriate technology.*

The structural steel project team used 2D drawings to build a steel detailing model, while the architecture team used a 3D modeling program, Revit Architecture. According to the Structural Project Manager with KL&A, using 2D models is conventional practice. The Structural Project Manager with KL&A stated that opportunities were missed by using 2D models for steel detailing. The Structural Project Manager with KL&A believes that using a 3D model, "really reduces the amount of time required to do the structural detailing." KL&A offers more integrated and advanced technologies that were not used on this project.

KL&A's Integrated Steel Delivery (ISD) method utilizes 3D models that are integrated with analytical models. KL&A will link their 3D model to other programs such as ETABS or RAM Structural System that will transfer the structural steel data into Revit

Architecture. This information will then update the tags, measurements, and any other relevant information in Revit. The Structural Project Manager with KL&A also stated that the informed Revit model can benefit the steel detailers, as it is easier and quicker to build a steel detailing model from Revit than with a 2D model. By using more appropriate technology, KL&A estimates a total savings of two weeks to one month.

#### *4.1.1.4.3 Utilize BIM among project team members.*

Building Information Modeling (BIM) allows the project team to approve drawings and models electronically (National Institute of Building Sciences, 2007). PVS's Chief Engineer shared that this technologically is highly beneficial for the structural steel team, especially the fabricators, structural engineers, and steel detailers. BIM allows the team to view an as-built rendering of the structure, see all structural information and measurements by clicking on a building component, and check for errors before constructing the physical building (National Institute of Building Sciences, 2007). The architecture team opted not to use BIM on this project and utilized Revit for architectural modeling.

During construction there were a couple areas where the expansion joints between the two different wings of the building were further apart in the field than they had appeared to be in the 2D drawings. The problem became apparent to the team only after the physical building components were built and in place. There was a change order that came out of the issue. PVS had to re-detail, fabricate, and transport new material, which LPR had to then re-erect.

This problem might have been avoided if the project team had been able to view a virtual model of the building before construction. The Chief Engineer with PVS stated, "I

think that if the project would have been done more in BIM, that particular issue may have been seen during the process and we would have picked it up before we actually put it up on the site.” The Chief Engineer with PVS stated that the virtual model might have also been useful for energy modeling and could have been used as a tracking tool for operations and maintenance.

#### ***4.1.1.5 Applying lessons learned.***

Participants mentioned two opportunities for improvement that involved applying lessons learned to the possible future wing of the NREL RSF project. The following scenarios describe the details of this theme.

##### ***4.1.1.5.1 Obtain feedback from LPR on areas that they struggled with during erection.***

The Detailing Manager with KL&A suggested that the project team obtain feedback from LPR on areas that they struggled with in erection and incorporate solutions into the design of the possible future wing.

##### ***4.1.1.5.2 Use the same project team for the future wing of NREL RSF project.***

Haselden Construction’s Project Manager stated that there is great opportunity in doing things the same way and using the same project team for a possible future wing of the NREL RSF project. Now that everyone is comfortable with each other, the team can build on the lessons learned and have an even smoother and more efficient process.

#### ***4.1.1.6 Implications of delivery method.***

Although there were only two comments about this theme, these comments touch upon many of the inherent issues that came up in this project. The following section describes these two opportunities for improvement.

4.1.1.6.1 Utilize a more integrated steel delivery process.

Several team members touched upon communication, design, and general delivery issues in their individual interviews. The Structural Project Manager with KL&A alluded that the root of these problems is the delivery method of the structural steel. The Structural Project Manager with KL&A spent a large portion of the interview speaking about a more integrated method to deliver structural steel.

KL&A has developed their own steel delivery method, which, for the purposes of this paper will be known as Integrated Steel Delivery (ISD) (see Figure 8). KL&A bid on the NREL RSF project as an ISD method, but was not awarded the contract under those conditions. Instead, KL&A was hired under two separate contracts at two different times in the project.

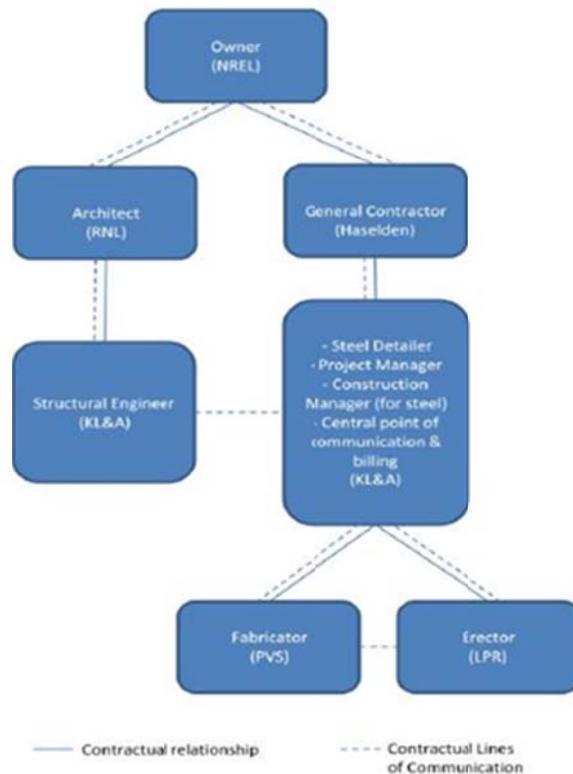


Figure 8. Proposed integrated steel delivery model.

The Structural Project Manager with KL&A explained that generally a client will ask KL&A to provide structural engineering and structural steel services for a job. KL&A is equipped to offer engineering services and construction management of the structural steel. This allows KL&A to manage all the billing, project management (concerning on-site steel construction), and steel detailing. KL&A will also hire the fabrication team and erection team. The Structural Project Manager with KL&A explained that this system allows the construction entity to leave all steel-related items to KL&A. Furthermore, because KL&A has ample experience with fabricators and steel detailers, they will sometimes get a preferred customer rate, which can decrease the cost of the project.

Under an Integrated Steel Delivery method, KL&A's construction management team will be involved in the structural steel design phase to ensure the most cost efficient design. The detailers, fabricators, and erectors are also involved early on in design. The Structural Project Manager with KL&A stated:

The detailers are involved early on to make sure that they have the information that they need and can provide their input as far as what's needed when to deliver on a certain date. Another thing is the fabricator and erector is typically known before construction documents go out so we can make sure all of the connection details are set up for their shop.

This is very cost effective, as it avoids substitution requests after the construction documents are complete or increased costs due to design errors. The Structural Project Manager with KL&A also believes the extra upfront work allows for a smoother construction process down the road.

Additionally, communication between the structural engineers, detailers, fabricators, and erectors is also improved by using ISD since KL&A has a direct contract with the fabrication and erection team (see Figure 8). The team can pick up the phone and

call each other directly about an issue without having to go through a long chain of command first. The Structural Project Manager with KL&A believes practicing an ISD method increases the speed and productivity of a job allowing the delivery of a project to be months quicker than in a traditional design-bid-build system. It is important to note that KL&A has been developing their ISD method for fifteen years and has used it successfully on past projects.

#### *4.1.1.6.2 Complete the design of a structure in its entirety before beginning construction.*

This project was sequenced so that the design and construction phases would be complete for section A first, section B second, section C third, and so on through section F (see Figure 4). As a result, PVS fabricated the steel according to the sequencing of the project (i.e. section A, then section B, etc.). According to the Chief Engineer with PVS, fabricating steel in sequences produces an excess of material waste. For example, after receiving an order for section A, PVS would nest the steel on a larger piece of steel about 8'x8'. Section A might use 25% of the sheet of steel. The remaining portions, the drop, are then set aside until the order for section B comes through. At that point, PVS will pick up that same large sheet of steel and nest section B. The sheet, however, now has odd shapes cut out of it from section A and it is harder to make a tight configuration on the sheet for all the pieces of section B. This process is repeated until all sequences have been fabricated. Ultimately, this leads to oddly-shaped cut outs that cannot be nested, which end up in the scrap yard. In fact, a concurrent study on the environmental impacts of the design, fabrication, and erection of the structural steel for the NREL RSF project considered this very issue. The white paper, "Greening Structural Steel Design, Fabrication, and Erection: A Case Study of the National Renewable Energy Laboratory

Research Support Facilities Project” analyzed the steel fabricated by PVS in 2008 and determined that the typical waste factor for a given unit fabricated product was 8.4%. This percentage may seem low, but that 8.4% waste factor equates to 75,200 kg of CO<sub>2</sub> emissions and 966,000 MJ of energy produced (Guggemos, Plaut, Bergstrom, Gotthelf, Haney, et al., 2010).

The Chief Engineer with PVS stated that there could be less waste in the fabrication process if the entire project were to be designed first and then the entire project was to be detailed. This would require a lot of lead time to have the design finished and permanent. In turn, this allows materials to be fabricated all at the same time regardless of sequence and the erection process. A fabricator could survey all necessary pieces for a project and then nest them on the large pieces of steel in the most optimal way. This might mean that a piece from section A is getting nested and fabricated with a piece from section D, but it would result in less wasted steel than if a fabricator were to nest all materials in sequences.

Fabricating steel in this fashion would save raw materials (which has direct costs all the way back to the steel mill), which would also eliminate waste being sent to the scrap yard. This method would also optimize the energy needed to pick up the steel sheets and place them on the burning table, as fabricating in sequences creates a lot of movement. PVS’s Chief Engineer stated that movement is time and energy, which equates to money. PVS has fulfilled job orders in this method before, and the Chief Engineer with PVS estimated, “We’ll have about 20% more waste if we don’t get to take advantage of that and just run it all at the same time.”

The Chief Engineer with PVS went on to talk about how steel can be delivered to a site when it is not shipped in sequence. If pieces A-Z were fabricated at one time and the project required them to be sent out in sequences, a fabricator could group pieces A-F together in a holding yard so that they could easily and quickly be picked up and trucked to the job site. Another alternative would be to send the entire order to the job site and have a big enough lay-down area for the fabricated steel so the crane could pick the pieces without having to move. Either way, PVS's Chief Engineer promotes the fact that fabrication can be most efficient when all materials are fabricated at the same time rather than in sequences.

#### ***4.1.1.7 Transportation of steel.***

Transportation of steel to the job site can have a great impact on the environmental footprint of a project. The following issue summarizes one opportunity for improvement for lessening that impact.

##### ***4.1.1.7.1 Utilize local manufacturing companies for production.***

The Chief Engineer with PVS shared that the environmental impacts of transporting steel can be reduced by utilizing manufacturers that are close to the job site. KL&A fabricated and shipped large bundles of steel from the PVS fabrication plant in Omaha, NE. However, all miscellaneous steel was fabricated by Coretec, Inc. in Loveland, CO. Loveland is approximately 57 miles away from the site, where as Omaha is approximately 547 miles away (MapQuest, 2010). This allowed for savings in transportation cost and fuel.

#### ***4.1.1.8 Mechanical systems.***

Two of the participants spoke to concerns with the mechanical systems for the

NREL RSF project. However, only one of the issues was relevant to the delivery of structural steel. The relevant opportunity for improvement is discussed below. The remaining three issues are summarized in Future Research.

#### *4.1.1.8.1 Early definition of mechanical systems.*

RNL produced a 3D image of the building during construction. The modeling program, NavisWorks, flagged an area in the data center where the duct work was too large and thus not compatible with the trusses. The project team spent about one week deciding if they could redesign a few trusses to engineer larger openings for the ducts to pass through the trusses. RNL consulted PVS on the matter, but ultimately determined that there were no feasible short term solutions. RNL decided to use the trusses as they were originally designed, but completed a fair amount of architectural and mechanical coordination to alter the mechanical design to fit within the trusses. The Project Manager with RNL estimated that it took about three weeks to resolve this issue from start to finish.

The Project Manager with RNL believes this problem could have potentially been avoided if RNL could have gotten the mechanical engineer to define their systems during preliminary design. The Project Manager with RNL stated, “If we could have gotten a mechanical engineer out front to define the system for the data center in more detail earlier that would have gone a long way to eliminate that structural conflict that we ended up with.” The mechanical engineers, however, were continuously behind the rest of the design. Due to the energy performance demands for the project, the mechanical systems were changed several times. The Project Manager with RNL stated that it was not an option to wait for the mechanical engineers to catch up because of scheduling demands.

The Project Manager with RNL concluded that mechanical systems defined later in design can lead to design, construction, scheduling, and cost issues later in a project.

#### **4.2 Focus Group Session**

During the focus group session, participants had the opportunity to view the results of the individual interviews (see Appendix III). All participants were brought together to determine the feasibility of three process recommendations for the future wing of the NREL RSF project. In order to determine the process recommendations, the suggested opportunities for improvement were synthesized into common themes. While there were ultimately several recommendations for the future project, time constraints only allowed for three process recommendations to be discussed during the focus group session (see Appendix IV). The three process recommendations were determined by two factors: (1) those with the largest amount of suggestions and (2) the theme's relevance to the structural steel industry.

Together, the researcher and focus group participants decided that the following process recommendations were the most common and relevant themes affecting the structural steel delivery process:

1. Establishing direct lines of communication among the structural steel team.
2. Ensuring early involvement of the erection team and fabrication team in the steel delivery process.
3. Utilizing appropriate technology.

Each process recommendation will be presented as a synopsis of the discussion during the focus group session. Focus group participants will be referred to by the title of

their profession for confidentiality purposes. Most of the focus group participants also participated in the individual interviews with the exception of the Senior Superintendent with Haselden Construction, the Project Manager with Paxton & Vierling Steel (PVS), and the Principal Engineer and Engineering Manager with KL&A, Inc. As a reference, Table 5 lists each participant, their associated company, and field of service.

**Table 5. Focus group session participants, associated companies, and fields of service.**

<b>Focus Group Session Participant</b>	<b>Company</b>	<b>Field of Services</b>
Project Manager	RNL	Architecture
Project Manager	Haselden Construction, LLC	Construction
Senior Superintendent	Haselden Construction, LLC	Construction
Project Manager	LPR Construction	Erection
Chief Engineer	Paxton & Vierling Steel (PVS)	Fabrication
Project Manager	Paxton & Vierling Steel (PVS)	Fabrication
Principal	MKK Consulting Engineers, Inc.	Owner Representation
Detailing Manager	KL&A, Inc.	Structural Engineering
Principal Engineer	KL&A, Inc.	Structural Engineering
Engineering Manager	KL&A, Inc.	Structural Engineering

**4.2.1 Process recommendation #1: Establish direct lines of communication among the structural steel team.**

The communication hierarchy for the NREL project was determined first by the project's contractual arrangement and second by the trust dynamics within the team. The project was contracted as a Design-Build (D/B) partnership between Haselden Construction and RNL Architects. Even though the project used a D/B method, the

fabrication and erection of the structural steel was more closely aligned with that of a Design-Bid-Build (DBB) method. Once Haselden Construction was hired, the steel fabricators, detailers, and erectors were brought on via a hard bid. Figure 6 illustrates the D/B contractual arrangement used for this project.

The project team agreed that the D/B contractual arrangement was more beneficial to the project than a traditional DBB model would have been. The Principal Engineer with KL&A stated, “If you're talking about the overall Design-Build [method], it is way, way ahead of the traditional Design-Bid-Build in terms of communication.” However, the structural steel team members including the structural engineers, steel detailer, fabricators, and erectors felt that the delivery method was an inferior contractual arrangement. The primary concern was that direct lines of communication did not exist between all structural steel project team members causing a series of inefficient interactions, one of which was unnecessary lag time processing Requests for Information (RFIs). While the fabrication entity, PVS, encouraged open communication between parties, not all project team members had practiced such open lines of communication. Haselden Construction’s Project Manager stated, “It's not that they couldn't [communicate]. It's more that we didn't because we didn't understand the process well enough to know the benefits of doing that.” The Senior Superintendent with Haselden Construction spoke to his inexperience with open lines of communication stating, “it was a little bit new and a little bit uncomfortable at first.” Thus, it took some time to trust in a system that varied from more traditional hierarchical methods.

The D/B delivery method posed challenges to the communication among project team members. D/B allows for design and construction to occur simultaneously, with

design consistently a few steps ahead of construction. The expedited D/B schedule provides a limited time to review designs so that construction can stay on schedule. Hence, there was not always adequate time to make sure communication needs were being met for all stakeholders.

Project team members agreed that although there were a handful of communication issues, there was still a relatively integrated steel delivery process because of the relationships among team members. The Engineering Manager with KL&A stated, “We did have some integration along the communication because we all know one another's work through various projects. We have the relationships.” All of the team members’ companies had worked together previously, which allowed for a level of trust that would be uncommon for a project team who had not previously worked together. Once trust was established between all the individual project members, they were more willing to directly communicate with each other, despite the contractual arrangements (See “Actual Lines of Communication” in Figure 6). The Principal Engineer with KL&A shared, “We talked with all five of those entities [design team, detailing crew, erectors, fabricators, and contractors] completely outside of the contractual arrangement because that's how we work.” There was also a consensus that if a company unfamiliar to the steel team had been hired, the project would have encountered additional challenges. They believed that their team was able to avoid problems due to the established working relationships between companies. This highlights the correlation between a trusting relationship within a project team and the success of a project.

Although project members established some level of integrated communication throughout the project, it was not until after construction documents had been issued that the majority of direct communication between the structural steel team members took place.

Despite the team's ability to work around their contractual arrangements, there were times that team members did not communicate directly with each other due to their contractual relationships. The Principal Engineer with KL&A stated:

Even though there are dotted lines going to all these different parties, we all understand that in this particular case Paxton-Vierling had responsibility for the structural steel erection and detailing and construction. When issues come up where that's important, we absolutely make sure that everything follows the right contractual channel.

Given the possibility that a different project team may not have an established level of trust, and thus be willing to communicate outside the contractual arrangement, KL&A presented an alternative contractual model (see Figure 8). This model allows for direct lines of communication among all structural steel project team members and has been used successfully on another project with Haselden Construction, PVS, and LPR. The Detailing Manager with KL&A supported the ISD model stating, "This scenario, we've had a lot of success with."

The Integrated Steel Delivery model establishes one firm as the structural engineer, steel detailer, project manager, construction manager (for steel), and the central point for communication and billing. The structural engineer hires the fabrication team and erection team directly, thus housing all structural steel team members under one party and establishing direct lines of communication. In this arrangement, the steel detailing team would be able to directly communicate with the structural engineering team. In

contrast, a steel detailer would not need to go through the fabricator, general contractor and architect to communicate with a structural engineer in the contractual arrangement illustrated in Figure 6. One potential benefit of an integrated steel delivery method would be savings in paperwork, time and energy associated with RFIs (Requests for Information) for smaller design questions. It is important to note that RFIs would still be required on issues that affect the project budget and schedule. Smaller design questions, however, would be able to be answered in a matter of hours versus days or sometimes weeks. The Principal Engineer with KL&A stated, “I think there's no question that in any situation better communication results in more efficiency which can translate into sustainability as well.” A savings in time equates to a savings in money, resources, and energy.

#### **4.2.2 Process recommendation #2: Ensure early involvement of the erection team and fabrication team in the steel design phase.**

During the focus group interview, there was a consensus that it would have been beneficial to include the fabrication team and erection team earlier in the design phase of the NREL project. Fabricators and erectors bring a unique perspective to the table, as they are able to foresee design issues that other team members may not recognize. The fabrication entity (PVS) and erection company (LPR) were not contractually brought onto the NREL RSF project until the end of the design development phase; therefore, the design was substantially complete before any input was gathered from PVS or LPR. The Project Manager with Haselden Construction shared, “Rarely does the fabricator, erector, or detailer have the opportunity to get feedback to the designer until it’s [the project] way

down the road. They can come up with an idea and maybe that would be very cost effective.”

During the focus group interview, project team members spent a significant amount of time discussing a truss girder size change that occurred during erection. Due to the increased member size, the crane that LPR was using was now too small to erect the new truss. Haselden Construction had to get a bigger crane, which was inefficient for LPR, as there were cranes moving in and out of an already constrained job site. Switching cranes was a disruptive element to the process and LPR suffered at least a one week delay because of the issue.

Although there were several scenarios discussed that could have resulted in avoiding this issue, the group did agree that if LPR and PVS had joined the steel delivery team earlier in the design, the team may have been able to get preliminary information about the joists and the team could have worked out girder allowances during preliminary design. The Chief Engineer with PVS suggested:

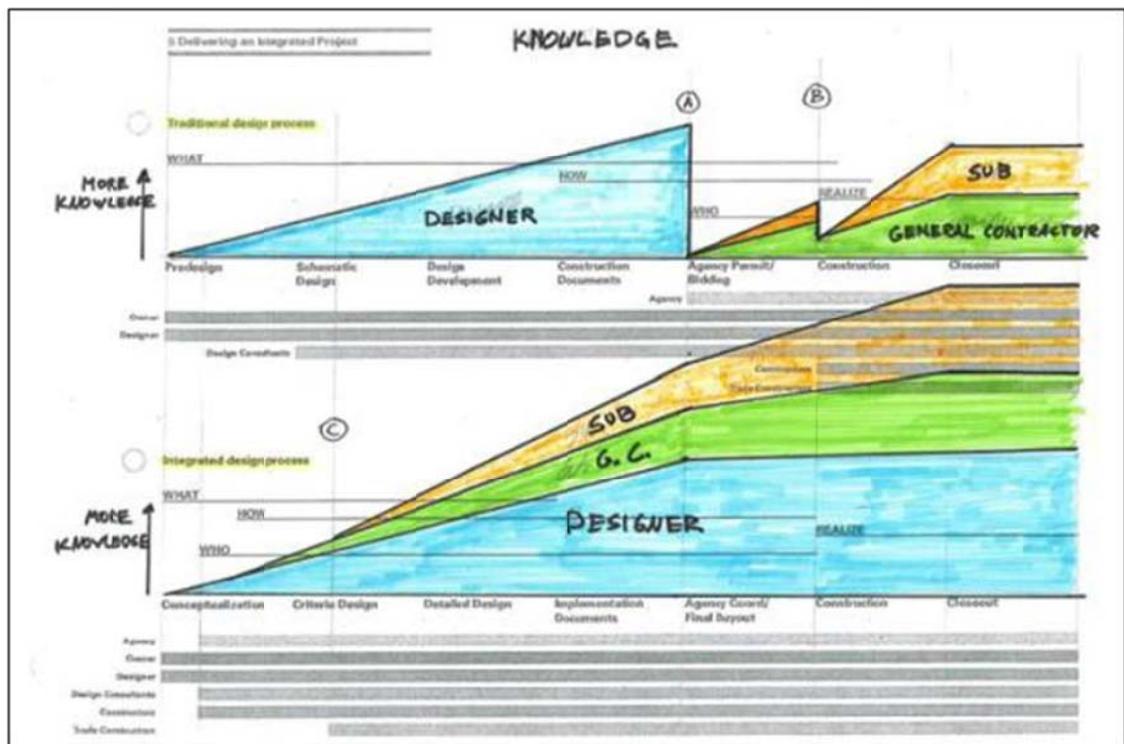
If you bring all the players on in a more classic early involvement, one thing the steel fabricator will try to do is find joist manufacturers that will give us preliminary information and we would get that kind of stuff worked out in a preliminary design world.

This would allow PVS to foresee any fabrication issues, Haselden Construction to order the proper crane, and would have eliminated the delays LPR suffered during erection.

Beyond including the fabricators and erectors earlier in the design of the project, the group also discussed the importance of involving all key stakeholders early in the project. Participants specifically suggested included the contractors, engineers, preconstruction team, and field crew early on in a project. The early involvement of key stakeholders in a project allows for holistic design decisions and the opportunity to work

through issues early in the life a project. Changes in design that are explored during schematic design and design development are generally less expensive and have a smaller impact on the schedule. Conversely, changes made during the creation of construction documents and the construction phase can have a much greater effect on the project resulting in a series of events that will use more time, money, resources, and energy to compensate for the design change (AIA National & AIA California Council, 2007).

A broad discussion of the implications of involving key stakeholders early in a project can be exemplified through Figure 9 as provided by KL&A (AIA National & AIA California Council, 2007; Rutledge, 2009).



I

Figure 9. Early involvement diagram (AIA National & AIA California Council, 2007; Rutledge, 2009).

The top graph plots the level and path of knowledge for a traditional delivery method. The project begins with a design team building knowledge of a particular project from predesign to the construction documents phase. Then, traditionally, the project will go out to bid. At that point, the general contractor (if they were not involved early) and the subcontractors will work extremely hard for a short amount of time in order to learn the project so that they may produce a competitive bid. Once awarded, the project then gets handed off to the construction team who has to relearn the project yet again. Each drop in the line of knowledge represents the drop in energy and understanding of the entity that is dedicated to the project. The Detailing Manager with KL&A stated, “What that drop signifies is the energy moves from the design team to the construction team and they literally are starting at zero. They have no clue what's going on.”

Conversely, the second illustration depicts the level and path of knowledge for an integrated delivery method. The graph shows that if the team members (i.e. primary stakeholders as well as subcontractors such as the fabricator and erector) are brought onto a project sooner, the team will acquire a higher level of knowledge about the project congruously. This eliminates a drop in knowledge at the transition between project phases. This drop can result in inefficiencies as a result of multiple knowledge transfers.

The group agreed that early involvement would be beneficial, but an integrated effort would be null if the exchange of information between phases was not smooth. Haselden Construction echoed this concern, noting that a smooth handoff between the preconstruction team (of which PVS was a member) and the field crew (of which LPR was a member) is sometimes overlooked. The Senior Superintendent with Haselden Construction shared, “We also have a little bit of a segregation there... We need to somehow improve that communication and build that trust back through there.” Early

involvement of both parties is extremely important to ensure that a loss of knowledge does not occur when the preconstruction team hands off the project to the field crew. Once again, early involvement of the fabrication team and erection team might have narrowed the gap in knowledge between the two parties.

The group discussed implementing a more integrated delivery model for future projects and concluded that the biggest impediment to the integrated model is trust. The Principal Engineer with KL&A stated, “The main impediment to this early involvement is trust. And it's not does the [General Contractor] trust LPR? It mainly has to do with the delivery method.” Often times, the owners and general contractors feel that they can get the best price by competitively bidding a project, which automatically excludes certain delivery methods. Furthermore, the established practices of the construction industry can often make an integrated process much more difficult, since including a wide range of project team members early in the process is not standard industry practice. Such a practice will take time to establish credibility in the eyes of a conservative industry.

#### **4.2.3 Process recommendation #3: Utilize appropriate technology.**

Utilizing appropriate technology, such as Building Information Modeling (BIM), can greatly enhance the sustainability of a project. Building Information Modeling has the ability to track several project components including scheduling, sequencing, deliveries, and the erection progress. Utilizing a 3D model also allows for initial problem detection virtually rather than on site. Corrections can be made before construction begins allowing savings in time, money, and resources (AIA National & AIA California Council, 2007). The Project Manager with RNL shared, “The more we do in 3D obviously the better off we are.” Furthermore, 3D modeling allows the erectors to

visualize connections better and understand the project more quickly. Steel detailers can also benefit from a 3D building model because they can model a detailed component including the weld or even a washer.

The NREL project team utilized several different software applications. Although almost every entity produced a 3D model of the building, they were all created using different software programs. RNL built their model in Revit, Haselden Construction used NavisWorks, and KL&A used SDS/2 by Design Data. The project team experienced interoperability issues that prevented them from sharing files and developing a comprehensive building model. The Project Manager with RNL explained, “I’ll speak to Revit, which couldn’t model the steel. It couldn’t model these truss girders...there was a gap in the ability of the software to represent the structure.” The Engineering Manager with KL&A stated, “I’m not sure how much experience there’s been in sharing models across lines of scope of work.” Interoperability issues are not always linked to the software applications, however. Often, it is the inability of the translator that exists between the two applications.

No one denied that better use of technology could have been applied; however, the way in which to do that was a main point of discussion. Short term, the team found that the simplest interoperability fix would be to take advantage of the model that the steel detailing team creates in order to approve electronic drawings instead of relying on hard copies. KL&A did have some success utilizing electronic documents, thus reducing the amount of resources used to create and transport paper documents.

One strong recommendation that came from KL&A and PVS was for the team to hold a technology planning meeting early in the project. The Detailing Manager with

KL&A supported this notion stating, “You have to have a plan up front on how this information is going to be transferred and shared. Otherwise you spend a whole bunch of your time just managing models and transferring data.” If the team chooses to use 3D modeling or BIM, the first thing to do is set modeling expectations within the team. The American Institute of Architects (AIA) and Associated General Contractors (AGC) have both written governing documents to help project teams determine what those expectations should be [see (Associated General Contractors of America, 2008; Eastman, Liston, Sacks, & Teicholz, 2008)]. Second, the team will need to understand what each software program is capable of producing, and identify any interoperability issues for the different software applications. Finally, it is important to define the level of modeling that each party is interested in providing, and then assign specific components to project team members. A dedicated planning effort is the key to successful collaboration.

Long term, companies will need to invest in more appropriate technology that can house multiple software applications. The goal is to successfully transfer knowledge from one team member to another, thus reducing errors and waste as a result of interoperability barriers.

## **Chapter 5: Conclusions**

### **5.1 Research Summary**

#### **5.1.1 Research problem and research questions.**

The Structural Steel industry provides the world with one of the fundamental construction materials, steel, yet, produces negative byproducts such as greenhouse gas emissions, energy consumption, and consumes nonrenewable resources as part of material production. While the steel industry has made commendable progress over the past twenty five years to reduce their environmental impacts (World Steel Association, 2008), there still remains room for improvement, particularly in the delivery process of structural steel.

Currently, the majority of the structural steel industry uses traditional delivery methods to execute design. Construction industry professionals are realizing the drawbacks of such systems, such as adversarial relationships between project team members, delays in design and construction, and increased costs. The industry is now exploring the opportunities provided by components of Integrated Project Delivery (IPD) (Cross, 2008). By using IPD, the structural steel industry has the potential to create less waste, such as reducing the amount of excess material produced, cutting back on fabrication and erection errors, and requiring less Requests for Information (RFI). A vital component of achieving less waste, and thus less of an environmental impact, is to include all key and secondary stakeholders in the design phase of a project. Key

stakeholders are defined as the owner, architect, and constructor. Secondary stakeholders include the steel fabricator, erector, engineer, and detailer (AIA National & AIA California Council, 2007). There has been a limited amount of research conducted on the value of including secondary stakeholders, particularly the fabricator and erector, in the design phase of structural steel.

The researcher based this study on a building for the National Renewable Energy Laboratory (NREL), the Research Support Facilities project - a 222,000 square foot office structure located at NREL's South Table Mountain campus in Golden, Colorado (National Renewable Energy Laboratory, 2010b). Results of this study were intended to provide information that would allow the structural steel industry to better understand current processes and possible opportunities for reducing the environmental impacts associated with the delivery of structural steel.

This study therefore set out to answer the following research questions:

1. What are the opportunities and efficiencies that exist as a result of using components of Integrated Project Delivery as used on the NREL Research Support Facilities project versus a traditional delivery method (refer to section 5.2)?
2. What are the benefits of including secondary stakeholders in the design phase of structural steel for the NREL Research Support Facilities project (refer to section 5.1.3.3)?

### **5.1.2 Methodology.**

In order to answer the proposed research questions, the researcher used a qualitative approach. Qualitative research was most appropriate for this study as there was a central phenomenon, the delivery process for the NREL building, which required a

deeper understanding due to the limited amount of literature on the topic.

Data was collected through a series of eight individual interviews and one focus group session with twelve NREL project team members (see Table 2). During the individual interviews, the researcher gained a general explanation of the structural steel delivery process, level and frequency of communication among team members, level of involvement, and types and amount of inefficiencies and opportunities for the NREL project.

During the focus group session project team members were given the opportunity to discuss the feasibility of three suggested opportunities for improvement based on the results of the one-on-one interviews (see Appendix IV). The three process recommendations were determined by two factors: (1) those with the largest amount of suggestions and (2) the theme's relevance to the structural steel industry.

The researcher then analyzed the results of the interviews, listening to each interview and taking copious notes from which common themes emerged. These themes have formed the key ideas of the findings.

### **5.1.3 Findings.**

#### ***5.1.3.1 Individual interviews.***

Data analysis revealed many opportunities for improvement for reducing the environmental impacts associated with the delivery of structural steel. The individual interviews revealed the following themes and subsequent opportunities for improvement.

#### *Construction Issues*

- Cranes to be handled by the erection team

- Increased site access
- Have power to the site before construction begins
- Weld the deck to steel instead of fastening the deck to concrete
- Use wedge anchors for deck support instead of epoxy anchor bolts
- Use of steel stair cores rather than concrete stair cores
- Increase coordination for steel and concrete components
- Increased quality control

#### *Communication*

- Allow the steel detailing team and structural engineering team to openly communicate throughout the entire project
- Establish a contractual line of communication between the steel detailing team and the erection team
- Direct lines of communication between the fabrication, erection, steel detailing, and structural engineering team
- Equal interaction among the owner's representation team and the design team
- Increased understanding of the gas pipe columns
- Earlier communication between the structural steel team members
- Earlier coordination and approval of section F of the RSF project

#### *Early Involvement*

- Work through potential issues early on in design
- Utilize the fabricator's perspective
- Consult the erection team for sequencing decisions
- Take advantage of each stakeholder's diverse knowledge

- Address architectural and structural concerns simultaneously
- Obtain manufacturer feedback

#### *Technology*

- Utilize electronic documents
- Utilize more appropriate technology
- Utilize BIM among project team members

#### *Implications of Delivery Method*

- Utilize a more integrated steel delivery process
- Complete the design of a structure in its entirety before beginning construction

#### *Applying Lessons Learned*

- Obtain feedback from LPR on areas that they struggled with during erection
- Use the same project team for the future wing of NREL RSF project

#### *Transportation of Steel*

- Utilize local manufacturing companies for production

#### *Mechanical Issues*

- Early definition of mechanical systems

#### **5.1.3.2 Focus group session.**

Following the individual interviews, participants were brought together to determine the feasibility of three process recommendations for the future wing of the NREL RSF project. The three process recommendations were determined by two factors: (1) those with the largest amount of suggestions and (2) the theme's relevance to the structural steel industry.

Together, the researcher and focus group participants decided that the following

process recommendations were the most common and relevant themes affecting the structural steel delivery process.

*Establish direct lines of communication among the structural steel team.*

- The existing contractual lines of communication did not allow for communication between all structural steel project team members, which led to inefficiencies and waste.
- An alternative contractual model was presented, Integrated Steel Delivery, which allows for direct lines of communication among all structural steel project team members.

*Ensure early involvement of the erection team and fabrication team in the steel design phase.*

- The focus group revealed that early involvement of the fabricator and erector would be beneficial to the overall efficiency of the structural steel delivery process.
- Participants also discussed the importance of including *all* key stakeholders early in a project such as the contractors, structural engineers, product manufacturers, and steel detailers.
- Early involvement and an integrated process would be null, however, if the exchange of information between phases is not smooth.

*Utilize appropriate technology.*

- Building information modeling has the ability to track several project components including scheduling, sequencing, deliveries, and the erection progress. Utilizing a 3D model also allows for initial problem detection virtually rather than on site.

- One strong recommendation that came from KL&A and PVS was for the team to hold a technology planning meeting early in the project. A dedicated planning effort is the key to successful collaboration.

#### ***5.1.3.3 Benefits of including secondary stakeholders in the design phase.***

A key finding for this study was in response to the second research question: what are the benefits of including secondary stakeholders in the design phase of structural steel for the NREL Research Support Facilities project? The findings from the individual interviews and the focus group session revealed several benefits of including secondary stakeholders in the design phase. Although AIA defines secondary stakeholders as all primary design consultants and subcontractors (i.e. steel fabricator, erector, engineer, and detailer), this study focused solely on the benefits of including the erector and fabricator (AIA National & AIA California Council, 2007) .

The most prominent benefit discussed was the unique perspective and knowledge that the erector and fabricator can bring to the design table. More specifically, interview participants mentioned that the erector and fabricator could bring insight about sequencing, site layout, types of connections, connection hardware, general best practices, optimizing materials, and cost effective solutions. In addition, the erector and fabricator may be able to foresee potential conflicts between structural and architectural features.

Participants also discussed the general outcomes of including the erector and fabricator in the design phase, which speaks to the benefits of early involvement. Including the erector and fabricator early in the design of a project could lead to fewer delays, less field errors, earlier detection of design issues and conflicts, cost savings, a

shorter construction schedule, holistic decisions, less waste, and a smoother transfer of knowledge between project phases.

## **5.2 Moving Towards Integrated Project Delivery**

At the start of this research, the intention was to determine the opportunities and efficiencies that exist as a result of using components of Integrated Project Delivery (IPD) as used on the NREL Research Support Facilities project versus a traditional delivery method. The researcher asked several questions during the individual interviews in an effort to determine (1) whether or not the project used IPD as stated (Personal Communication, 2009) and (2) what level of IPD was practiced. For example, the researcher asked interviewees about the project's contractual arrangements, communication patterns, sequencing of the building and structural steel design and construction, the phase at which each respondent was brought onto the project, their perceived level of integrated design for the structural steel, and level of early involvement (see Appendix II).

Participants revealed several facts that countered the use of IPD. For example, the researcher learned that even though the overall project used a Design-Build (D/B) method, the delivery of structural steel was actually more closely aligned with that of a Design-Bid-Build (DBB) method. Participants also shared that there was not early involvement of all key stakeholders and that there were not always open lines of communication. Furthermore, many participants were unaware of the meaning of Integrated Project Delivery and Integrated Design. In fact, KL&A continually referred to their own steel delivery method, integrated *steel* delivery, as integrated *project* delivery, unaware that they are separate methods. The researcher also learned that the project was reported to use an integrated design method (National Renewable Energy Laboratory,

2010c) only because the mechanical engineers and lighting consultants were involved early on in the project. Thus, it was an obvious deduction to conclude that the NREL RSF project did not use Integrated Project Delivery. The researcher is therefore unable to identify opportunities and efficiencies that exist as a result of using components of Integrated Project Delivery as used on the NREL Research Support Facilities project versus a traditional delivery method.

Interestingly enough, however, KL&A's proposed Integrated Steel Delivery (ISD) method incorporates five of the nine principles of Integrated Project Delivery (*Integrated project delivery: a guide*, 2007):

1. Early Involvement of Key Participants
2. Intensified Planning
3. Open Communication
4. Appropriate Technology
5. Mutual Respect and Trust

### **5.2.1 Early involvement of key participants.**

Integrated Project Delivery promotes bringing team members other than the owner and designer on to a project much earlier than that of a traditional delivery process. The AIA Council & McGraw Hill (2007) suggests considering the involvement of the following participants, "Owner, Operator/User, Designers (architects/engineers), Contractors, Subcontractors, Suppliers, Equipment manufacturers, Systems integrators, and Lenders". Collaboration between team members may increase a project's sustainability by reducing the amount of time needed for documentation, working with a more accurate cost estimate and schedule, increasing the efficiency of the construction

phase, and possibly decreasing the amount of time needed for construction. Additionally, because there is an increased effort at the early stages of a project, early involvement could lead to fewer on-site errors, requests for information, change orders, and less wasted time spent on communication (AIA National & AIA California Council, 2007).

Under an Integrated Steel Delivery method team members other than the owner and designer are brought on during the design phase of a project. More specifically, the detailers, fabricators, and erectors are brought on early, as each member brings a different set of knowledge and expertise to the table. For example, the detailers provide valuable input on the needs of their team in order to meet the construction schedule. The fabricators and erectors also work with the steel detailers early on to ensure that the connection details are arranged in the most optimal way for the fabrication shops and erection team. Similar to IPD, ISD can be quite cost effective, as it avoids substitution requests after the construction documents are complete or increased costs due to design errors.

### **5.2.2 Intensified planning.**

An increased amount of design effort during the beginning phases of a project (through Detailed Design) results in less design effort during the latter half of a project (through Construction phase) (see Figure 4). Less design effort, and thus less design changes, towards the end of a project is highly beneficial to a project's budget and schedule, as the ability to impact cost and functional capabilities greatly decreases towards the end of a project's life and the cost of design changes greatly increases towards the end of a project's life. Integrated Project Delivery appropriately assumes the greatest amount of design effort towards the beginning of project, allowing team

members to collaborate, communicate, and innovate while the project budget and schedule is still relatively flexible and can absorb change better than towards the latter half of a project's life (AIA National & AIA California Council, 2007).

Integrated Steel Delivery practices an intensified planning effort, which is a result of including the steel detailers, fabricators, and erectors early on in the design of a project. Naturally, involving more key players early in a project will lead to an intensified planning stage, as there will be many issues that need to be worked out among all project team members. KL&A believes the extra upfront work allows for a smoother construction process down the road.

### **5.2.3 Open communication.**

Integrated Project Delivery upholds that team performance is dependent upon receptive and honest communication between all participants. It is imperative that all team members understand and practice an open policy for sharing information, which can then lead to more frequent and successful collaboration efforts. Furthermore, this principle encourages responsibilities to be assigned with the understanding that team members practice a no-blame culture. Well-defined and allocated responsibilities allow problems to be identified and solved more effectively, rather than resorting to liability. A policy of open communication should be supported by the contractual arrangements (AIA National & AIA California Council, 2007).

While the information gathered through the individual interviews and focus group session does not touch upon assigning responsibilities or liability, Integrated Steel Delivery does promote open lines of communication between all structural steel team

members. Open communication is reflected in the ISD contractual arrangement (see Figure 5).

Under an Integrated Steel Delivery contractual arrangement, KL&A is hired for their engineering services and as construction manager for the structural steel. This allows KL&A to manage all the billing, project management (concerning on-site steel construction), and steel detailing. KL&A will also hire the fabricator and erector. Because KL&A contractually oversees all steel-related items, this also houses the structural engineer, detailer, fabricator, and erector under one entity. Therefore, structural steel team members are contractually allowed to openly communicate with one another. Team members can pick up the phone and call each other directly about an issue without having to go through a hierarchical chain of communication first, as is the case with most traditional delivery methods.

#### **5.2.4 Appropriate technology.**

Integrated Project Delivery can be greatly aided by using advanced technologies such as computer modeling. Technologies are utilized at the start of a project and are utilized to improve functionality, simplicity, and must be operable between project disciplines. A detailed computer model allows the project team to identify errors, assess the constructability of a project, and modify the plans before construction begins, thus reducing and potentially avoiding errors on site. Building Information Modeling (BIM) is highly suggested, although not absolutely necessary, as a tool to execute IPD (AIA National & AIA California Council, 2007).

The success of Integrated Steel Delivery is also greatly aided by using appropriate technology. ISD promotes using integrated and advanced technologies, such as 3D

models, that are integrated with analytical models. For example, KL&A will link their 3D model to other programs such as ETABS or RAM Structural System that will transfer the structural steel data into Revit Architecture. This information will then update the tags, measurements, and any other relevant information in Revit. This allows the engineer and architect to work from the same model. Furthermore, the steel detailers also greatly benefits from a shared model, as it is easier and quicker to build a steel detailing model from a 3D model than with a 2D model.

### **5.2.5 Mutual respect and trust.**

Establishing mutual respect and trust among project team members is a preliminary step towards successful collaboration in Integrated Project Delivery. The AIA National and AIA California Council (2007) require that the owner, designer, constructor, consultants, subcontractors and suppliers value collaboration and commit to working towards the best interests of the project. Team members must think beyond their own individual goals, and base decision-making upon larger project goals and outcomes. This shift in thinking is contradictory to many traditional project delivery methods. It is therefore imperative that a project team begin establishing mutual respect and trust from the very beginning of a project (AIA National & AIA California Council, 2007).

Integrated Steel Delivery (ISD) appropriately encourages hiring all structural steel team members early on in a project. Integrated Steel Delivery also encourages open communication and early collaboration, which allows team members to cultivate their working relationships early on and establish trust. Integrated Steel Delivery builds on the correlation between a trusting relationship within a project team and the success of a project.

Integrated Steel Delivery also allows project team members to develop knowledge of a project congruously by hiring all structural steel team members early in a project. This can encourage team members to work towards project goals from the same level of knowledge as other team members.

### **5.2.6 Remaining principles.**

While Integrated Steel Delivery is a step in the right direction towards fully adopting Integrated Project Delivery, there are still four other principles of IPD that need to be accounted for.

1. Mutual Benefit and Reward - All participants and team members benefit from the success of IPD. Furthermore, compensation and incentives are based on the value an organization adds to achieving the project goals.
2. Collaborative Innovation and Decision Making - Collaborative innovation occurs when all participants exchange ideas without restraint. The project team also assesses key decisions, which are to be made unanimously when practical and feasible.
3. Early Goal Definition - Goals are defined early in the project, and team members must agree upon and respect project goals. Project goals are to shape the basis of individual team member objectives and values.
4. Organization and Leadership - Leadership for certain tasks is assigned to the best-suited team member depending on the type of work and requirements.  
  
Furthermore, team member roles are clearly defined in a way that supports open communication and risk taking (AIA National & AIA California Council, 2007).

While ISD might be incorporating components of the remaining four principles, the data from the individual interviews and focus group session did not reveal any information as such. Therefore, the researcher cannot make any conclusions about the inclusion of the remaining principles within Integrated Steel Delivery. It is also important to note that even if KL&A adopts all nine principles of Integrated Project Delivery, project team members outside of the structural steel team (architect, engineer, owner, etc.) will also need to adopt all nine principles as well in order for a project to truly practice IPD.

The data on Integrated Steel Delivery presents enormous potential for the structural steel industry to move towards Integrated Project Delivery. The fact that the structural steel industry as a whole is already moving toward integrated design practices and utilizing BIM puts them ahead of the curve (Cross, 2008). Together, the current practices of the structural steel industry and Integrated Steel Delivery are paving the way towards adopting all components of Integrated Project Delivery. Similar to adopting IPD, however, the entire project team will need to adopt an Integrated Steel Delivery method in order to realize the benefits. The structural steel industry can reduce their environmental impact through early involvement of project team members, collaborative communication, an increased planning effort during critical design phases, and utilizing appropriate technology. These practices will ultimately lead to higher quality products and processes with less waste and more environmentally and economically efficient outcomes.

### **5.3 Future Research**

Areas for future research became apparent throughout the course of this study. Some are the observations of the researcher, some are deduced from the limitations of

this study, and others were suggested by interview participants. This section discusses three main areas for future research.

The first research question for this study was not able to be answered due to the fact that the NREL RSF project did not actually use Integrated Project Delivery. However, the researcher was able to determine great value and potential in Integrated Steel Delivery as a means to move towards adopting IPD. ISD already incorporates four out of the nine guiding principles of IPD. Future research should evaluate the current status of the structural steel industry as it relates to the five guiding principles of IPD that are not incorporated in KL&A's Integrated Steel Delivery method. In order to fully practice and realize the benefits of Integrated Project Delivery, a project must incorporate all nine guiding principles (AIA National & AIA California Council, 2007).

Another important component of this study is to determine the actual value of incorporating the suggested opportunities for improvement. A future research project could follow the delivery of the additional wing of the NREL RSF project, Section F (see Figure 7), and study the effectiveness of the incorporated opportunities for improvement. Data could be obtained through interviews and a quantitative analysis could be performed to determine the environmental impacts of the newly incorporated practices. The determined environmental impacts could then be compared to the Life Cycle Assessment data from a previous study that looked at sections A-E, "Greening Structural Steel Design, Fabrication and Erection: A Case Study of the National Renewable Energy Laboratory Research Support Facilities Project".

Lastly, future research could be conducted on the mechanical systems of the NREL RSF project. The Principal with MKK Consulting Engineers suggested three

alternatives to the current mechanical system during the individual interview:

1. The building currently has a large amount of controls for the building's thermal comfort system. The Principal with MKK Consulting Engineers pointed out that the more electrical controls that are installed, the more possibilities there are for errors. Future research could assess the feasibility of using fewer controls in the building's mechanical system.
2. The NREL RSF project is monitoring and measuring all the mechanical and electrical systems for the building. The Principal with MKK Consulting Engineers feels there was a missed opportunity by not installing a geothermal system for the building. Future research could conduct a site study and determine the appropriateness for a geothermal system for future projects. Since NREL is already monitoring and measuring all systems for the RSF project, it could be interesting to do the same for a geothermal system in a separate building and compare the energy efficiency between two different buildings.
3. The third suggestion by the Principal with MKK Consulting Engineers was to study the under floor air distribution system. Currently, the system is designed to circulate room temperature air only. The Principal with MKK Consulting Engineers was concerned about how the under floor air distribution system would be affected by the radiant heating in the ceilings. Future research could study the use of the distribution system to ventilate *and* cool air and how that is affected by the radiant heat system.

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## **Appendix I – Email Recruitment Email**

This e-mail is being sent to request your participation in a one-on-one interview and a focus group interview for a study conducted by Helene Gotthelf under the supervision of Dr. Angela Guggemos at the Department of Construction Management at Colorado State University. The purpose of this study is to determine the value of including secondary stakeholders in the design process of structural steel for the National Renewable Energy Laboratory (NREL) Research Support Facilities project. This study also seeks to identify best practices and recommendations for the integrated design process of a possible future NREL building as well as other buildings that rely heavily on steel.

You were carefully selected for participation in this study and I am very hopeful that you will agree to be a part of the interviews being conducted for this study. It is important to note that there are no right or wrong answers; rather I am interested in hearing about your experiences regarding the structural steel process for the NREL building. I feel that you are uniquely suited to assist in this study.

You will be asked to participate in 1 one-on-one interview and 1 focus group interview. The one-on-one interview is expected to last approximately 45-60 minutes. The focus group interview is expected to last approximately 90-120 minutes and will include the other participants in this study. In total, I am asking for no more than 3 hours of your time over the next 6 weeks. You will be asked to answer the following topic questions during the one-on-one interview:

1. What is your role within the project team?
2. What delivery method was used for the NREL project?
3. When were you brought onto the project and what was your level of involvement through each phase (i.e., Schematic Design, Design Development, Construction Documents, and Construction)?
4. What was the design process for the NREL project?
5. What was your level and frequency of communication among project team members (i.e., Owner, Architect, Engineer, Steel Detailer, Contractor, Fabricator, and Erector)?
6. What are some of the inefficiencies and opportunities for improvement within the NREL project?
7. Do you see any value in including the Fabricator and Erector in the design process?

Please note, each of the questions above has a series of sub-questions that will allow you to expand on each question and allow me to better understand your experiences throughout the design process. I am providing you with the topic questions for two reasons:

1. I am sensitive to your already busy schedule and am extremely appreciative of any time you can dedicate towards this study. I thought that it would be helpful for you to have the opportunity to review the questions before the interview.
2. By contemplating the answers ahead of time, it will ensure that we are both able to maximize the results of our 1 hour interview.

Please note that participation in this study is voluntary and there are no known

direct risks or benefits to the participants.

If you are willing to participate in this study please respond to this e-mail and let me know of your availability from 11/23/09 – 12/4/09. I will be scheduling the 1 hour one-on-one interviews during that 2 week period. If you are not able to meet during those dates, please let me know and we can make arrangements to meet at a time that is most convenient for you. I will schedule the focus group interview once all one-on-one interviews are complete.

The contribution that you will make is an essential component to gaining a better understanding of the current processes and possible opportunities for reducing the environmental impacts associated with the design of structural steel.

Thank you for your time and I look forward to hearing from you.

Sincerely,

Helene Gotthelf [helenengotthelf@gmail.com](mailto:helenengotthelf@gmail.com)

512-743-6303

## **Appendix II – Individual Interview Questions**

### **Objective 1: Determine respondent's role within the project team.**

- 1a. What is your title?
- 1b. What is your role within the project team?
- 1c. What are your contractual obligations for this project?

### **Objective 2: Determine project and structural steel delivery method of NREL project.**

- 2a. What is the delivery method used for the NREL project?
- 2b. What is the delivery method used for the structural steel for the NREL project?
- 2c. What is your contractual relationship to the project?
- 2d. What is the structure of communication between project team members (i.e. Architect, Contractor, Owner, Engineer, Steel Detailer, Fabricator, and Erector)?
- 2e. What is the order in which design and construction of the NREL building were executed?
- 2f. What is the order in which design and construction of structural steel were executed?

### **Objective 3: Determine when the respondent was brought onto the project and their level of involvement through each phase.**

- 3a. At what phase were you brought on to the project?
- 3b. Were you involved in the schematic design of the building?
  - 3b.1. If so, what services did you provide?
- 3c. Were you involved in the design documents phase of the building?

3c.1. If so, what services did you provide?

3d. Were you involved in the construction documents phase of the building?

3d.1. If so, what services did you provide?

3e. Were you involved in the construction phase of the project?

3e.1. If so, what services did you provide?

**Objective 4: Determine what the design process was for structural steel of the NREL project.**

4a. Who was involved in the design of the structural steel for the building?

4b. This project has been described as using an integrated design process. Setting this project aside, what does an integrated design process mean to you?

4c. Have you been involved in a project before that utilizes an integrated design process?

4d. Was there an integrated design effort for this project?

4d.1. If so, did you see any benefits from using an integrated design process?

4d.2. If so, did you see any negative outcomes from the integrated design process?

4e. Was there an integrated design effort, specific to the structural steel, for this project?

4e.1. If so, did you see any positive outcomes from the integrated design process?

4e.2. If so, did you see any negative outcomes from the integrated design process?

**Objective 5: Determine level and frequency of communication among project team members in regard to the structural steel delivery (i.e., Owner, Architect, Engineer, Steel Detailer, Contractor, Fabricator, and Erector).**

5a. Who did you communicate with the most?

5a.1. Why did you communicate with this person the most?

5a.2. How often did you communicate with this person on a weekly basis?

5b. Who did you communicate with the least?

5b.1. Why did you communicate with this person the least?

5b.2. How often did you communicate with this person on a weekly basis?

5c. Is there a project team member(s) that you would like to have communicated with more?

5c.1. Why or why not?

5c.2. What were the barriers that kept you from communicating with this person?

5d. Do you think the end product, the NREL building, was affected at all by the lines of communication among project team members?

5d.1. If so, how was it affected in a positive way?

5d.2. If so, how was it affected in a negative way?

**Objective 6: Specific to structural steel, determine inefficiencies and sustainable opportunities for improvement within the NREL project.**

6a. Did you deal with any specific inefficiencies throughout the project as it relates to structural steel?

6a.1. If so, please give a brief description of the problem.

6a.1.a At what phase did they occur: schematic design, design development, construction documents, fabrication, erection, and/or construction phase?

6a.1.b Which parties were involved?

6a.1.c Please describe what you believe to be the cause of the problem.

6b. Did you notice any opportunities for improvement throughout the project as it relates to structural steel?

6b.1. If so, please give a brief description of the opportunity.

6b.1.a At what phase would that come into play: schematic design, design development, construction documents, fabrication, erection, and/or construction phase?

6b.1.b What parties would it involve?

**Objective 7: Determine if project team members see value in including the structural steel fabricators and erectors in the steel design process.**

7a. Do you think that this/these inefficiencies could have been avoided or lessened if project team members communicated more with each other throughout the entire project?

7a.1. Why or why not?

7b. Specific to the structural steel design process, when do you believe communication should begin among team members?

7b.1. Why?

7c. Do you think that this inefficiency could have been avoided or lessened if the fabricator was involved in the design process?

7c.1. Why or why not?

7d. Do you think that this inefficiency could have been avoided or lessened if the erector was involved in the design process?

7d.1. Why or why not?

**Objective 8: Determine lessons learned for a possible future NREL project.**

8. Are there any lessons learned from this project specific to the structural steel design process?

### **Appendix III – Summary of Individual Interviews**

The following list represents the Opportunities for Improvement that were gathered from all individual interviews. The researcher emailed this list to each of the eight individual interview participants. Participants had one week to respond with any comments. The researcher informed the participants that if they did not respond the researcher would assume their approval for accuracy. It is important to note that during the development of this study the researcher further synthesized the thirty-six opportunities for improvement to thirty opportunities for improvement. No opportunities for improvement were removed. Rather, they were combined with others to avoid redundancy.

#### **All Opportunities for Improvement (36 total)**

##### Construction issues (10)

- **Cranes to be handled by the erection team:** The erection team is best suited to determine their own carnage needs.
- **Increased site access:** Restricted site access can hinder the erection process.
- **Have power to the site before construction begins:** Electrical power will lessen the amount of diesel generators on site.
- **Weld the deck to steel instead of fastening the deck to concrete:** Deck to steel is a more stable connection, as fastening the deck to concrete causes damage to the concrete and slows down production.

- **Use wedge anchors for deck support instead of epoxy anchor bolts:** It is more efficient for the erection team to use wedge anchors, as the epoxy anchor bolts take more time to install.
- **Use of steel cores rather than concrete cores:** It is quicker and cleaner for the erector team to work with steel cores rather than concrete cores.
- **Have power set up on job site early on:** Electrical power on site decreased the need for diesel generators.
- **Increase access points at job site:** One access point hinders erection efficiency.
- **Increase coordination for steel and concrete components:** More upfront planning and coordination might result in fewer complications in the field.
- **Increased quality control:** This decreases the likelihood of errors in the field.

#### Communication (7)

- **Open lines of communication across all project team members:** Issues are resolved in a timely manner when project team members can directly communicate with each other.
- **Direct line of communication between the steel detailing team and the erection team:** A steel detailer is often working on components that will directly impact the erection team and require feedback.
- **Earlier communication between the steel detailers, fabricators, joist manufacturers, EOR, and the erectors:** The structure's framing situation presented some unusual connections, which required early input from the above parties.

### **Increased communication between the owner's representation team and the design**

- **team:** The Principal with MKK Consulting Engineers's role did not include upfront design input, rather the scope of work only included verification after design decisions were already made.
- **Direct lines of communication between the fabricator, erector, and structural engineer:** This allows issues to be resolved in a timelier manner and rework to be lessened.
- **Improved communication between the erector and contractor:** This will allow for a smoother erection process and fewer issues in the field.
- **Increased communication between LPR and KL&A concerning gas pipe columns:** Because of the unique nature of the structure, increased communication can avoid confusion among project team members.

### Early involvement (6)

- **Involve the Contractor, Fabricator, and Engineer early on in the project:** Early involvement between the three team members can lead to more coordination early on, the opportunity to ask more questions, and the potential to resolve any issues early on.
- **Upfront coordination with Fabricator during design:** The fabricator can foresee potential conflicts between the design and structural steel frame.
- **Involve the erector in sequencing decisions:** The erection team can offer valuable insight towards potential conflicts between project sequencing and erection.

- **Involve the fabricator and steel detailer early on in design:** The fabricator and steel detailer can add valuable insight to the design of the connections.
- **Early involvement of the structural engineer and fabricator in design:** Both project team members can offer valuable insight to potential conflicts between the design and structural frame of a project.
- **Obtain manufacturers' feedback during design:** The manufacturers can offer valuable information concerning production and delivery times.

#### Mechanical systems (4)

- **Explore a different application of the mechanical system:** Use the floor plenum for ventilation and cooling.
- **Use less controls in the building's thermal comfort system:** A high amount of controls can equate to more opportunities for errors.
- **Consider a geothermal system for the new wing:** Geothermal energy could present an opportunity to compare different systems between RSF 1 and RSF 2.
- **Early definition of mechanical systems:** Mechanical systems defined later in design can lead to design, construction, scheduling, and cost issues later in a project.

#### Technology (3)

- **Utilize electronic documents:** A limited paper trail allows for environmental savings.
- **Utilize technology that is more appropriate:** Opportunities were missed by using 2D drawings for the steel detailing model.

- **Utilize BIM among project team members:** BIM allows project team members to detect errors virtually, which can reduce construction issues in the field.

#### Applying lessons learned (2)

- **Obtain feedback from LPR on areas that they struggled with in erection:**  
Incorporate solutions into the design of the possible future wing.
- **Use the same project team for the future wing of NREL RSF project:**  
There is great opportunity in doing a project twice with a similar project team.

#### Design and delivery method (2)

- **Utilize a more integrated steel delivery process:** KL&A is equipped to manage a more integrated steel delivery process, which could result in communication and a delivery process that is more efficient.
- **Complete the design of a structure in its entirety before beginning construction:** Fabrication can be most efficient when all materials are fabricated at the same time rather than in sequences.

#### Transportation (1)

- **Utilize local manufacturing companies for production:** Miscellaneous steel was fabricated in Loveland, CO rather than Omaha, NE.

#### Miscellaneous (1)

- **Earlier coordination and approval of the new wing of the RSF project:** Late design decisions can cause wasted material, rework, and increased costs

## **Appendix IV – Focus Group Session Agenda**

### **11:00-11:15 Welcome & Introductions**

- Name, organization, role in project

### **11:15-11:25 Research Project Overview**

- Research Partnership and Initiative (KL&A)
- Colorado State University (Josie & Helene)
- Focus Group Objectives
  - Gather scenario analysis information
  - Discuss process recommendations

### **11:25-11:40 Scenario Survey**

### **11:40-12:50 Process Recommendations & Lunch**

- Summary of themes from interviews (Helene)
- Direct lines of communication among structural steel team (20 min)
  - Issues: contractual arrangements, existing communication hierarchy, girder connection labor costs, crane size
  - Possible benefits: fewer design, delivery, and construction issues, cost efficient design, smoother communication, integrated design, and quicker project delivery
  - Feasibility?
- Early involvement of the erector and fabricator in the steel design process (20 min)
  - Issues: erection and fabrication sequencing, connection design (particularly between gas columns and joists), labor costs, truss girder depth, fastening deck to concrete, epoxy anchor bolts
  - Possible benefits: fewer design and construction issues, earlier coordination, reduced costs, increased efficiency within the erection and fabrication process, less re-work, and a more integrated design
  - Feasibility?
- Appropriate Technology (20 min)
  - Issues: 3D models not integrated with analytical models, expansion joints between building wings

- Possible benefits: allows the project team to approve drawings and models electronically, identify constructability issues virtually, quicker and easier steel detailing model, smaller paper trail
- Feasibility?

- **12:50-1:00 Wrap Up**

## **Appendix V – Partial Transcription of Individual Interviews**

Theme	Subtopic	Detailing Manager, KL&A: November 25, 2009
Construction Issues	Increase coordination for steel and concrete components	<p>1:11.32: C: One of the things that we really identified in this project is the coordination of the steel and concrete... mainly fit up between concrete where embeds were misplaced...I think Haselden identified some inefficiencies in their system, so they're working on that. I know our engineers are looking at maybe providing a different type of drawings that might outline information clearer.</p> <p>1:13.38: C: When we're looking at more ways to make that more efficient, you know what can we do as the design and steel team to make that happen better? Better communication, you can always communicate better.</p>
Communication	Allow the Steel Detailer and Structural Engineer to openly communicate throughout the entire project	<p>9:05.0: C: Typically, what you have to do is you have to go through this elaborate process of getting an answer to one question. In this case, I could pick up the phone and call the engineer in Golden..."</p> <p>11:35: C: If you have a fairly responsive design team usually that turn around can be 1 day, hours, weeks. I've had RFIs out for a month before.</p> <p>11:57: C: The other problem with the RFI system is the person on the other end of the RFI is subject to interpreting what I'm writing. So, if I'm not very clear on what the problem is and the proposed solution or request for an answer, many times the answer I get back doesn't even answer the question I was asking</p> <p>16:18: C: That's during the shop drawing process, ok. That's hashing everything out so I can get my answers. It's a little different when we've gone into fabrication and erection. H: OK C: Because now issues that are found in the field affect a lot of people. So, in that case, many times those lines of communication we follow traditional rules on that just to make sure everybody was in the loop.</p> <p>18:07: C: You know, I really didn't generate any RFIs on this project.</p>

	Establish a contractual line of communication between the steel detailer and the erector	42:40: C: I think on this project, um, I'm gonna make a confession. H: (Laughter) C: We called and talked to the erector quite a bit early on. We have a pretty established relationship with LPR and we know the importance of putting together something that's gonna help them. So, I called Joel on a couple different occasions to get some direct input on what he wanted to see us do because I knew we had to change some things. I figured, let's change them the way Joel wants them and I by-passed PVS on some of that stuff. H: OK. C: So the erector would be somebody that I would always like to have a direct line of communication with.
	Direct lines of communication between the fabricator, erector, steel detailer, and structural engineer	42:23: C: Well these are very complicated framing situations. We've got round columns. We've got joists sometimes framing in or sitting on them. We've got high transfer loads. We ended up resolving it by putting all the teams together. That's the only thing that I can think of on this project that if we would have done that just a little earlier would have made it more efficient.  1:14.23: C: Moving on to the next entire project, we always say we need to communicate more up front.
Technology	Utilize electronic documents	56:06: C: We used to produce about 5-6 sets of drawings to go through the review process and each reviewer would mark up their own set and then they would be carted back and forth between review teams.  57:10: C: The way we handled it was all of our submittals were done electronically to PVS.  58:23: C: You burn a lot of money and fuel shipping stuff
Applying Lessons Learned	Obtain feedback from LPR on areas that they struggled with in erection	1:13.56: C: Get some feedback from LPR on areas that they really struggled with in erection and maybe try to get some of that stuff incorporated into the design
Transportation of Steel	Utilize local manufacturing companies for production	59:30: C: One of the things that PVS did was they had a local fabricator do all the miscellaneous steel that we worked with directly for field fixes and things like that. So you don't have a couple embed plates coming out from Paxton Vierling in Lincoln, or Omaha

Theme	Subtopic	Principal, MKK: December 2, 2009
Communication	Equal interaction among the owner's representative and the design team	<p>40:18: H: Is there anybody that you would have liked to communicate with more that you thought would have been beneficial?</p> <p>C: Actually, I would have liked to have communicated more with the designer and have our input almost instantaneously of how things are moving along...I would have like to ask them how they were going to approach an issue on the building before they got into it and then we could brainstorm...It's more like they designed, we reviewed, we input, they changed, we reviewed and input. So it was kind of a jerky...it wasn't as fluid as I thought integrated design could be.</p> <p>45:05: H: So then on this project, what I'm hearing you say is that there wasn't a party at the table to challenge those decisions or bring up different options.</p> <p>C: Right. The decision was made and then we ask the question. And we were kind of limited in what we could ask because did they meet the RFP? Well, yeah, but what about this other option? You kind of always wanted to say, well, have you looked at this?</p>
Early Involvement	Obtain manufacturer feedback	<p>25:47: H: And who would you define as being part of the project team?</p> <p>C: I would say you could break it up into three different elements. If you wanted to add another one you could do that. The owner, the design team, which would be the architect, all the engineers, and the consultants whether they be interior designers or whatever, let's put them in the design team. And then the contractor. And the fourth one you might involve would be the manufacturer's of the product because if we make decisions on design that say we want to use this type of product, well the contractor has to go to the manufacturer and say, "how long does that take to get here"? So it might be a great product, but the timeline is way out of line...So if you were going to have it totally integrated, I would say you get the manufacturers or the reps involved at the table also.</p> <p>31:19: C: We need to have them explain their product to the team to get buy-in from the owner or the contractor. Maybe the contractor has never installed this type of equipment before and he's not really comfortable with it.</p>

Mechanical Issues	Explore a different application of the mechanical system	<p>54:58: H: For this building, are there any specific components that you think could have been done differently?</p> <p>C: Yes</p> <p>H: Like what?</p> <p>C: The mechanical system is, I think, inefficient...The biggest thing for me is that it is an under floor air distribution system that's just for ventilation. H: What would you have done?</p> <p>C: Well you can use that part of it to ventilate and cool the core. I don't have a problem with the system, but the way that they applied it...you have 12 inches blowing through the under floor and coming up through circular diffusers or whatever...Well the bottom of that plenum is the ceiling of the space below. That's where all the radiant tubing is and this radiant tubing could have water up to 130 degrees and down to about 60 degrees. Well the air in this plenum is supposed to be neutral air. It's just ventilation. It's supposed to be whatever the temperature in the space is. It's not supposed to influence temperature. It's just for ventilation. So you have 70 degree air in this plenum and you have concrete with tubing in it, and as far as I understand physics haven't changed, and so you have 100 degree temperatures in the slab. What's it going to do to this air in between here? It's going to influence that temperature. So now you're pulling cooling out of that, which should be going down on into the space below. There's no insulation between there. There's no buffer space between there. To me, that's inefficient because it's going to heat up that air and then it's not going to go down.</p>
	Use less controls in the building's thermal comfort system	<p>59:18: C: There's lots of controls. A lot of controls. But what you're really looking for is simple. Simplify everything. You're pulling outside air from the side wall; you could be pulling it from the labyrinth underneath the building. You could be pulling it from directly outside. Or now, you could pull it from the data center. So now all these places have got to be monitored for which one is the best place to pull it in and all these moving parts of where the air is coming in. The more multiples you have, the more chances you have for something going wrong. You probably could have simplified</p>
	Consider a geothermal system for the new wing	<p>1:05.07: C: I was actually talking to Doug earlier about how the structure and mechanical system could work together on a geothermal system. If they were drilling piers, or caissons and stuff like that, they're drilling down 50 feet or whatever for their caissons. Can we put tubing in their concrete when they're pouring their caissons? And then we can use that as a geothermal source. That's really integrating the structure with the mechanical system.</p>

Theme	Subtopic	Project Manager, Haselden: December 11, 2009
Early Involvement	Work through potential issues early on in design	14:27: E: We certainly learned doing this process that we would have had more involvement between the contractor, fabricator, and the engineer up front. In hindsight, there were maybe better questions to ask and more coordination early on. We were able to work out a lot of those items later once we started to understand the process better. Its cliché, but that paradigm shift of doing an integrated project team just took a while to understand. All members were enthusiastic and wanted to embrace that as much as they could, but then you have decades of experience doing it a different way and people just didn't realize some of the opportunities we might have had as early as we wish we could have...It's not as much they weren't talking to each other, rather open them up to communication and understanding the amount of influence each can have on the other.... Between could and actually doing and being comfortable and really working together - that happened, but it just took a little bit for everyone to fully embrace that.
	Utilize the fabricator's perspective	20:57: E: Another item was coordination with the joists - the fact that we had to keep our joist depth pretty low because of all the day lighting in the building. That was an item to work through...It was an upfront issue of the design-build process where members weren't specifically sized early early on. We just knew the general loads they had to carry. The general assumption was this joist will carry the sufficient load. Then we realized that specific joist doesn't work. H: Did the fabricator get involved in the conversation? E: They subbed the joist to Carlisle I believe and through coordinating with those folks they were able to find a double joist or some other way to make it work.
Applying Lessons Learned	Use the same project team for the future wing of NREL RSF project	27:16: H: Any other opportunities for improvement that you can think of considering the new wing of the building? E: I think a lot of the opportunity is doing it the same. This is a unique building. When you have an opportunity to do things as close to the way you just did them you can take all that experience and roll it straight forward. You can get a lot of efficiencies out of that.

Theme	Subtopic	Structural Project Manager, KL&A: December 3, 2009
Communication	Increased understanding of the gas pipe columns	<p>14:53: J: I think there are some areas that can be improved...I think having a set crew of engineering people that work very closely with their fabricators. That really provides a lot of value during design because you can pick up the phone and call the fabricator when you have a question in design development or construction documents...With experience, engineers get to know what is cost effective, but there's so many different shop processes and shops are set up differently, that you may think you're doing the right thing and it's actually doing it some other way. So it's really nice to know who the shop is.</p> <p>16:22: J: It's also great to have the detailing staff so close to the engineering staff because it makes the detailing process so much better. You can deliver a project much faster because if you're both designing and detailing the job you can start your detailing model and detailing much sooner in the process...The detailers provide great input...You can deliver a project months quicker than in design-bid-build.</p> <p>26:53: H: Thinking about those project team members, was there somebody you would have liked to communicate with more on this project?  J: Just having done these integrated projects the KL&amp;A style, it's very nice to have the fabricator and erector at your disposal for questions or comments especially during construction. You spend less time going through the loops of communication to make sure everybody's involved with everything...Everything goes through the architect that I send out. The architect sends it to the contractor. Then the contractor sends it, if it's a steel issue, to Paxton Vierling. Then Paxton Vierling would send it to the steel detailer. Well, on this job the job the steel detailer was part of KL&amp;A and the structural engineer was part of KL&amp;A and you couldn't just walk down the hall or shoot them an email. There was some of that. There's always going to be for quick questions, but if anything of any substance was being decided, it would have to go through that loop of communication, which takes time...it could be anywhere from a couple days to a week or two.</p> <p>32:41: H: So can you think of any of those specific issues that happened on this project?  J: The joist girder is one that we were talking about earlier...Paxton Vierling had provided an overall price off of a specific set. Then Haselden had sent updated plans to them for a while and once they said give us your final price on this, some things had changed a little bit, as they will during design. PVS came back and said, "hey, here's an add service of so much for these connections because they weren't what we thought they would be".</p> <p>35:20: J: There was a long window there in between the initial price and the final price where</p>

		<p>there should have been a couple extra pricing sets in there as well...There was some resolution but it was once we were into the construction phase where things are not as easily changed.</p> <p>H: Once that problem became apparent, can you recall how long it took before it was resolved?</p> <p>J: It depends on what I would specify as solved. I would say it was at least three weeks to a month. There was rework. There were delays in the first sequence of steel delivery.</p>
Technology	Utilize more appropriate technology	<p>40:14: J: One thing that we can also offer in our integrated delivery method is, I mean, we build analytical models. We typically do jobs in Revit. So we have a 3D model that is integrated with our analytical systems model as well...We'll link it to another program like ETABS or RAM Structural System that will pull out the structural steel of the building. It will transmit the information back into the Revit model and update the tags and the information about the beams. We can go back and forth between Revit and Ram. What we offer is to also send that model to the detailers to input that in as an SDS2 model or whatever software they're using. That really reduces the amount of time required to do the structural detailing.</p> <p>44:01: H: KL&amp;A uses those programs, but you didn't do something like that on this project? J: That's correct. We did not. We have the capability.</p> <p>H: What was the process on this building?</p> <p>J: The process was the conventional process where the structural 2D drawings, paper or electronic, were used to build the steel detailing model from the ground. They start from scratch on the SDS2.</p> <p>H: As opposed to starting with the Revit model?</p> <p>J: Right</p> <p>H: How much time using Revit might save over using the building up from the 2D plans?</p> <p>J: Probably a couple weeks, at least.</p> <p>H: Total?</p> <p>J: Yeah, two weeks to a month probably.</p>
Design and Delivery Method	Utilize a more integrated steel delivery process	<p>18:10: H: I was reading the report to see what they did and they defined it as a structural engineer led delivery method. I read a little bit about it, but can you explain what it is to me?</p> <p>J: Yes. Typically what it is is a client will ask us to provide the structural engineering services and also provide the structural steel on the job. We sign up for the engineering services, also the construction management of the structural steel. We're running all the billing through KL&amp;A. We're running all the project management through KL&amp;A as far as on-site steel construction. We're doing all the steel detailing for the job and hiring the fabricator and hiring the erector. So really the contractor says, "Ok. KL&amp;A is doing the steel." They don't have to go out and take bids for fabricators or erectors or any of that. It's a whole package deal...We have bid out to fabricators and erectors before, but typically it's negotiated. The fabricators and erectors that have worked with us know the quality of work that we do and that we've got their back. A lot of</p>

		<p>times they will give us a preferred customer rate and so we can actually pull some costs out of the project as well...The construction management team is involved in our design as well during the design process to ensure that we're getting the most cost efficient design in there. Also, the detailers are involved early on as well to make sure that they have the information that they need and can provide their input as far as what's needed when to deliver on a certain date. Another thing is the fabricator and erector are typically known before construction documents go out so we can make sure all of the connections details are set up for their shop and make it most cost effective so we don't have either substitution requests after the construction documents are out or just increased costs due to people doing things the way they're not used to doing it.</p> <p>22:24: H: Why was that particular process not done on this building? J: It was looked at, but I believe it was a cost based decision.</p>
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Theme	Subtopic	Project Manager, LPR: December 1, 2009
Construction Issues	Cranes to be handled by the erection team	<p>21:38: J: Probably 75% of the time we bring the crane, the hoisting to the project...On this particular job, for some reason, the general contractor decided that he was going to provide the crane...The fact is he already made his crane selection and already had it on site and the next thing you know, it doesn't really work.</p> <p>H: What do you mean? J: Too small.</p> <p>H: Too small to erect the members that had been changed? So originally they were supposed to be smaller and then they became bigger?</p> <p>J: Yep. That's exactly what happened.</p> <p>24:50: J: It was a disruptive element to the process.</p> <p>27:16: J: I think we could have gone faster with a bigger crane...I think pretty easily we suffered a week.</p> <p>28:09: J: We tried to have a discussion with Haselden early on about crane and make sure we were all on the same page. It didn't seem to bear any fruit.</p> <p>29:11: J: To me the proof of the crane being too small is that you can't pick up and put a piece where it needs to go.</p>
	Increased site access	<p>26:15: J: This building also had some site issues that went along with that because it's kind of a land locked structure. Its H shaped and during the construction phases and erection phases, you couldn't get around that building. When we started on the west end, we were essentially trapped over there and you couldn't go and unload materials on the east end very easily. So there was a lot of inefficiency, I think, that was related to site constraints...access was pretty much always on the east side</p>
	Have power to the site before construction begins	<p>54:45: J: We ran our welder banks on 480 power that they provided. They didn't have enough power to provide for the nelson studs, for the generator...Every time you pulled the trigger on that gun a huge cloud of smoke would belch out into the air...The best deal is when you can get plugged into the grid if the jobsite has enough</p>
Communication	Earlier communication between the structural steel team members	<p>48:11: J: I don't have the insight into the what the design philosophy was that required the concrete. I've speculated a couple things. The one theory I have, I'm sure if I ask KL&amp;A Brett would tell me or Joe would tell me, but it either has to do with the fact that they used a material...the use of the recycled pipe was a design element that I think was addressing green philosophies, I think.</p> <p>Interview questions that Joel filled out before our interview: "I don't know why the concrete was required but it is a very unusual design concept."</p>

Early Involvement	Consult the erector for sequencing decisions	<p>31:03: J: Our sequencing of the project I think would have been different from what ended up. Somehow or another, the decision got made to sequence the job and the flow of erection...you know, if you look at the building (Joel is drawing a rough site plan for me), basically, being an H shaped building and being basically like this (points to drawing)...Well, instead of doing like 1, 2, 3, 4, 5 (pointing to drawn sections of building), we thought it would be so that it would require your crane to be here, here, and then go here, and then go all the way back here, and then come over and here and be here. We thought, well why don't you do here, you know, put the crane right here and have it do everything (pointing to drawing) and then move over here and do all that...If you wanted to optimize the job from our perspective, that's what we would have done.</p> <p>33:10: J: The discussion [with the contractor] never really happened...I didn't push it hard enough on one level.</p>
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<b>Theme</b>	<b>Subtopic</b>	<b>Chief Engineer, PVS: December 4, 2009</b>
Communication	Earlier coordination and approval of the new wing of the RSF project	<p>11:08: M: There was one thing toward the end of the project where the customer, NREL, decided to add yet another wing onto the structure. We were called towards the end - they called us and told us that they wanted to pull the trigger on adding the extra wing to the building, so we ended up putting a hold on all that material that was fabricated and complete, and it is physically being stored at our yard across the road. What is happening right now is the architect and engineer are doing their part to redesign the last connector area where the last wing we fabricated gets connected to the new building that is currently under design.</p> <p>30:09: M: I believe one thing the architect and engineer are trying to do is see if there are ways of reducing some of that material or salvaging it to use it in the new structure.</p> <p>H: At what point during this whole process of fabrication and construction did NREL decide to do this new wing?</p> <p>M: The original design was 95% finished. They were just onto interior finishing and maintenance to the structural steel. We were almost completely finished when we first starting hearing about the wing being a reality....we were probably 95% through the structure when they finally made the actual decision to add that last wing on. Everything was in motion and in the shop so we just finished the fabrication to avoid delays.</p>

<p>Early Involvement</p>	<p>Take advantage of each stakeholder's diverse knowledge</p>	<p>38:48: H: Were you guys involved in the design of the structural steel?  M: No. We were brought in after the initial design was done. But one thing that did happen, once we were on the design and under contract, we started looking specifically at the connections. We kept going back to the moment connections of the joist girders to the reclaimed pipes. We did a calculation on how much labor we thought was going to require for the original design shown to us by the design engineer. Since fabricators tend to be connection people by nature, we looked at them, gave them a price. It was a bigger number than they wanted it to be. They asked us to think about alternatives so we came up with some ideas of how to make that connection work differently. We worked collaboratively with the engineer to come up with ways to find some economy of the connection. The one that we collectively came up with is the one that was finally used and it did save some time on those connections both here in the shop and in the field.  H: Do you think that that could have been avoided at all?  M: I think it is always good practice to bring the fabricator and the detailer onto the design team long before the design documents are finished. Depending on the delivery system you're trying to describe, whether it's design-build or design-assist or the IPD that you hear about from time to time, all of those have a basic backbone of early involvement. If you can get the detailer and the fabricator, who have a different eye on what a building looks like than an engineer or an architect. Everyone's coming from their own silo of experience and concern. If they would have had the fabricator involved earlier on before anything was finished on paper, during the conceptual design phase, or when the engineer is working with his connections, yeah, I think there could have been a lot of improvements made there.</p>
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Technology	Utilize BIM among project team members	<p>5:03: M: We asked at the beginning of the project if we can take advantage of some BIM technologies where they're doing drawing approval electronically or model approval. The architect elected not to do that. They wanted to use the traditional shop drawing submittal process. That I think is a lesson learned that would be beneficial to explore whether that would be a more appropriate way to get drawings approved.</p> <p>12:17: M: When we work with projects where we're using BIM or sharing a model for approval, the engineers tend to be easy to sell for the idea because they get an opportunity to look at the as-built rendering of the structure in the model...I think an architect is not as concerned about that part of it, or that aspect of it. They're more concerned about things that might govern the coating system, for example. That's not something that a building model really portrays. Architects don't really have motivation to get into that world, to break the ice of learning how to do that, because they don't see what they're interested in. The engineers can see what they're interested in, but the architects really don't.</p> <p>16:01: M: There were a couple places where the expansion joints between the two different wings of the building, they were further apart in reality, in the physical world, then they had appeared to be on the 2D drawing that the engineer and architect generated. I think that if the project would have been done more in BIM, that particular issue may have been seen during the process and we would have picked it up before we actually put it up on the site...We did some re-detailing and there was additional material that was provided.</p>
Design and Delivery Method	Complete the design of a structure in its entirety before beginning construction	<p>57:01: You have the whole entire project designed and then the whole entire project detailed and then you have the ability to fabricate the material all at the same time regardless of the sequence and regardless of how it's going to be erected. Then have a mechanism later on to sort it when it comes to the job site...If you do all those previous things that I described where you can basically fabricate the whole building at one time regardless of how it's sequenced, then what you get to do is bulk more stuff together...if you think about a sheet of steel, which looks like a sheet of paper...I'm going to cut stuff out of that thing. If you have a sheet like that and you nest a lot more stuff on it, you can have less waste of that plate by the time you're done than if you nested in sequences. You would save raw material...We don't have that waste that we're then sending back out to scrap yard.</p> <p>1:03:29: H: Have you been involved in a project where you were able to do that?  M: Yes, we've done jobs that way.  H: Can you estimate the amount of waste saved?  M: We'll have about 20% more waste if we don't get to take advantage of that and just run it all at the same time.</p>

Theme	Subtopic	Project Manager, RNL: December 10, 2009
Early Involvement	Address architectural and structural concerns simultaneously	<p>31:27: H: I want to ask you about the floor to floor height that ended up being 6 inches less and then that affected the girder. Can you tell me more about that?</p> <p>M: A couple things happened. We were pressed on the budget side. One of the easier ways to reduce costs in a building is to limit the floor to floor height...As we lowered the sandwich of the building, the steel started to get in the way of the day lighting so we had to check all of that. We really wanted to see if we could reduce the size of the girders because when we flattened it out we had the bottom of the girders only 8'8" off the finished floor... We were a little worried that that beam would feel too low. One thing that frustrated the design team a little bit, both myself and KL&amp;A to some extent...is we didn't know what that truss girder actually looked like because it's the steel fabricator who designs that truss girder based on the loads the structural engineer gives them...That was a bit of a challenge for the project from the design side because that piece of the thing didn't really get designed until we were all ready to put it up.</p> <p>35:04: From a designer's perspective, I think I might have preferred to have KL&amp;A design a truss.</p> <p>38:15: Obviously the design is done just before the fabrication. The fabrication is key to getting it out there and keeping the project on its construction schedule. So there really wasn't a window that we could have said, "hey let's slow down and let's look at these things again".</p> <p>46:41: H: How do you think that could have been avoided?</p> <p>M: It would have taken during the early design phase, very early, a different decision about what that girder was. That decision would have had to happen right after concept or early in preliminary design.</p> <p>H: If the structural steel people were involved earlier on in the design, who would you think needed to be at that table?</p> <p>M: The fabricator and structural design engineer.</p> <p>H: With that issue can you say the amount of time from when the issue became apparent to when it was resolved?</p> <p>M: It didn't take much time at all. It was really a matter of the architect saying, "oh, well, I guess that's what it is." By the time the shop drawing for those things came through and we realized what they were truly going to look like, the construction schedule was beyond re-examining it.</p>

Mechanical Issues	Early definition of mechanical systems	<p>39:25: M: We found out that we had kind of a large bust in our data center. We had some large ductwork that was designed and it was kind of missed that that ductwork was not going to work with the trusses. Obviously the building was under construction. This was during the 3D coordination phase of the project. There's a NavisWorks model of the project that essentially builds it in 3D and this was flagged...In the end we basically told them that none of the solutions were good enough that we could use in the short term. So we had to use the steel as it was originally designed and we had to do a fair amount of architecturally and mechanically coordinated fixes for the mechanical design...That was probably the one area where we could have done better during design at trying to eliminate that conflict before we discovered it in the field.</p> <p>H: How do you think that problem could have been avoided?</p> <p>M: I think early on in preliminary design the mechanical engineer needed to define the systems they needed to support that room better than they did...If we could have gotten a mechanical engineer out front and define the system for the data center in more detail earlier that would have gone a long way to eliminate that structural conflict that we ended up with.</p> <p>43:59: H: Was there ever a suggestion to wait for the mechanical engineers to catch up before continuing on?</p> <p>M: We had a fixed deliverable date for the building and early in the process we lost a lot of the float that was in the construction schedule...So everybody was really working as fast as they could on all sides. Once you get a construction site up and going you can't stop it. It's not financially feasible.</p> <p>H: So when the ductwork issue came up, can you remember the amount of time it took to resolve the issue?</p> <p>M: From start to finish it was probably two to three weeks.</p>
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Theme	Subtopic	Site Superintendent, LPR: December 1, 2009
Construction Issues	Increased site access	<p>24:19: H: Any other opportunities that you can think of?</p> <p>R: Job site management a little bit, you know, just for access. I know that job gets pretty cluttered up with equipment. We almost got too much equipment on site sometimes. A lot of jobs are getting that way, just because of the schedule. You know, everybody's trying to work on top of each other. That's not really productive for anybody...productive, safe. That's the nature of the beast nowadays.</p>
	Have power to the site before construction begins	<p>21:48: R: The biggest thing on our parts is power on the jobs. Get power on the jobs sooner. I mean, when we don't have electrical power that's when we end up brining in generators and diesel welders...not only noise, but exhaust.</p> <p>23:05: R: And you know, a 250 Kwh has got about an eight inch exhaust pipe on it. H: That's pretty big.</p> <p>R: They got a 400 gallon diesel tank and we fill it about every other day.</p>
	Weld the deck to steel instead of fastening the deck to concrete	<p>5:46: R: Instead of welding the deck down, which is more stable, we had to shoot Hilti pins into the concrete, which is like a wedge going into a log. It blows up the concrete, and it's power actuated gun does it. It's not a good fastener.</p> <p>6:34: R: Probably takes 30%-40% more time. You do it the first time...And then you come back two days later after Colorado winters and Colorado nights and expansion and compression pops all those pins loose.</p> <p>5:06: H: Ok. Do you think that you could have had some influence when they were designing that and you could have brought up that issue?</p> <p>R: Oh yeah, yeah.</p>
	Use wedge anchors for deck support instead of epoxy anchor bolts	<p>7:54: R: The deck supporting one end of the crawl space is another issue. Instead of wedge anchors, they used epoxy anchor bolts...So you have to come in, put two wedge anchors in, hang your angle, drill the rest, wait 24 hours to tighten up all your nuts. So you lose a day there instead of just typical wedge anchors...The epoxy ones take quite a bit longer. It's another probably 50% savings if they went with wedge anchors.</p>

	Use of steel cores rather than concrete cores	<p>15:43: R: You can have concrete cores and you can have steel cores...We would rather see steel cores.</p> <p>H: Why do you like those better than the concrete cores?</p> <p>R: Because with steel cores, everything's going in the steel. When we put in our stairs or all the connections or column to column and our stairs go from landing to steel and we never connect the embeds. And then they come in and throw studs around it. It just makes it quicker and cleaner for us.</p>
	Increased quality control	<p>12:44: R: We had one column that was like a foot short. We had to add on it in the field.</p> <p>H: Do you think that those errors could even be avoided somehow? R: Yeah, you know, double check quality control.</p> <p>15:04: H: If something is wrong, or you know, there's a mistake there, well what happens?</p> <p>R: Well it stops work to begin with. You know, your raising gang...you got five guys there that shut down. And we try to survey ahead of time, and you know detail gets in there and put their clips on and we find embed troubles...Some of the girder fixes slowed us down a week to ten days.</p>

## **Appendix VI – Partial Transcription of Focus Group Session**

Recommendation	Discussion Topics	Detailing Manager, KL&A: December 22, 2009
Direct lines of communication among structural steel team	Team member relationships	<p>39:13.0: C: The uniqueness of the team we have together is that we've done work with Paxton Vierling and they're comfortable that we have their interest at heart, and I as a detailer can talk to our engineers and I'm not going to make decisions that's going to cost them money. And that is a trust issue that doesn't come naturally on a project without some history.</p> <p>42:35.4: C: I think the only way it worked in my opinion on this project is the team players we had on board...a lot of it is driven by the team we have in place rather than the contract.</p> <p>1:05:22.0: C: My feedback is, again, the only way this worked as well as it did was because of the team we put together. Otherwise, that model just looks a lot like a regular traditional construction model.</p>
	Integrated Steel Delivery method	<p>57:14.3: C: This scenario we've had a lot of success with, with OSP, but again, we put together a very precise team to make it work.</p> <p>1:30:12.4: C: We've been working on this system [OSP model] for fifteen years.</p>
Early involvement of the erector and fabricator in the steel design process	Early involvement of all key stakeholders	1:39:15.1: C: We encourage our contractors to be involved in a lot of our design choices because it's really nice to have the contractor stand up say, "Excuse me. You can sure do that, but you just added \$20,000 to the cost of the slab edge around the building." That's very valuable to the architect because they didn't know. They just made a design change. They didn't know it was going to have that big of an impact.
	Drop in knowledge	1:37:52.5: C: What that drop signifies is the energy moves from the design team to the construction team and they literally are starting at zero. They have no clue what's going on.
Appropriate technology	Technology planning meeting	<p>2:03:34.4: C: I think all the entities need to get together and put on the table what software they're using, what file formats exist for their software, and have a game plan put in place by Haselden or whoever the contractor is or whoever the controlling entities of these are decide on a specific file format that we all agree. You have to have a plan up front on how this information is going to be transferred and shared. Otherwise you spend a whole bunch of your time just managing models and transferring data.</p> <p>2:03:34.4: C: I think planning is key and getting everybody on board immediately out the gate.</p>

Recommendation	Discussion Topics	Project Manager, Haselden: December 22, 2009
Direct lines of communication among structural steel team	Open lines of communication	32:08.6: E: It's not that they couldn't [communicate]. It's more that we didn't because we didn't understand the process well enough to know the benefits of doing that.
Early involvement of the erector and fabricator in the steel design process	Early involvement of fabricator and erector	1:39:15.1: E: Rarely does the fabricator, erector, or detailer have the opportunity to get feedback to the designer until its way down the road. They can come up with an idea and maybe that would be very cost effective, but the whole building is now designed around that ineffective model. You can correct the small piece and save twenty grand here, but now it's going to have a huge impact on redesigning the rest of the project.
	Trust impediment	1:07:38.7: E: I don't have anything to add. Just the trust piece to reiterate and that's about it.
Appropriate technology	Interoperability issues	2:06:51.6: E: Another long term piece is that there's no industry consensus on what should be modeled and at what level of detail do you model what. There is benefit to the coordination effort, but it is tough to determine the exact level of detail to achieve an output that outweighs the input cost. We're still trying to figure that out in house. It takes a lot of time and guys that get paid pretty well. Where does that break even?

Recommendation	Discussion Topics	Project Manager, LPR: December 22, 2009
Direct lines of communication among structural steel team	Integrated Steel Delivery method	1:05:39.1: J: As far as the model of preference, I would say the OSP model has an advantage in my mind because you're adding an entity as far as a manager for the overall steel and this is part of the thing that I think has a bigger umbrella than in the non-OSP model.

Recommendation	Discussion Topics	Chief Engineer, PVS: December 22, 2009
Early involvement of the erector and fabricator in the steel design process	Girder allowance issue	<p>1:01:45.2: M: If you bring all the players on in a more classic early involvement, one thing the steel fabricator will try to do is find joist manufacturers that will give us preliminary information and we would get that kind of stuff worked out in a preliminary design world.</p> <p>1:03:02.4: M: The work that was performed by the joist manufacturer was taking the loads that are given to him at any given time in the process of his work and looking at the geometry that's allowed, i.e. the depth and the span. Then doing that calculation that we all know how to do as engineers. The sooner you can put that in front of the competent guy that specializes in joist design the sooner you're going to have that weight that took us by surprise.</p>
Appropriate technology	Steel Detailer's model	<p>2:02:52.7: M: That approval drawing- I think that would have been the simplest, lowest level interoperability we could have run through on this project. Just take advantage of the model that Camie made to approve the drawing and not doing it the traditional way of printing paper and moving paper around even if it is a PDF file.</p> <p>2:15:50.5: C: What Camie can do with SDS2 is amazing because she can model right down to the weld or the washer.</p>
	Interoperability issues	<p>1:58:05.6: M: There is a certain amount of interoperability that exists right now that goes from the manufacturing model, which is the steel detailer's model, into either NavisWorks or Revit Structures. Those translators are improving all the time, but right now they are very weak and that really tends to be the problem. As an industry, if we want to try and push this interoperability issue that we need in order to see the truss, there has to be a reason for software developers to define those entities more as they appear.</p>

<b>Recommendation</b>	<b>Discussion Topics</b>	<b>Project Manager, RNL: December 22, 2009</b>
Early involvement of the erector and fabricator in the steel design process	Early involvement of all key stakeholders	1:45:08.1: I'd love to see more integration between preconstruction and the field work on all levels by all contractors.
Appropriate technology	Interoperability issues	1:53:52.7: M: The more we do in 3D obviously the better off we are. We've got a lot of software limitations right now and I think the software just isn't as good as it should be...with each different model and each different software there was something that wasn't working right. I'll speak to Revit, which couldn't model the steel. It couldn't model these truss girders...there was a gap in the ability of the software to represent the structure...some of the coordination in 3D that should have gotten done couldn't get done because the model wasn't accurately representing the structural components.

<b>Recommendation</b>	<b>Discussion Topics</b>	<b>Senior Superintendent, Haselden: December 22, 2009</b>
Direct lines of communication among structural steel team	Design Build versus Design-Bid-Build	1:07:45.6: R: This one (DB model), if you could just modify it a little bit to open the lines of communication, I think this one works well.
	Open lines of communication	33:12.8: R: Once we're out here, once the design team and everyone was together and opened up the lines of communication, it worked well...and it was a little bit new and little bit uncomfortable at first.
Early involvement of the erector and fabricator in the steel design process	Early involvement of all key stakeholders	1:32:27.9: Josie: Would it have helped to sometime along the way have brought people together from KL&A and from across the spectrum and get everyone together in the same room and go through the design as it stood in a point in time? R: In hindsight, I think that would have been much more beneficial.
	Information exchange between phases	1:33:08.4: R: We also have a little bit of a segregation there. We have a preconstruction group and weren't always on the same page as our preconstruction...we didn't open the full lines of communication. We threw another party in place and it added a little bit of...We need to somehow improve that communication and build that trust back through there.

<b>Recommendation</b>	<b>Discussion Topics</b>	<b>Project Manager, PVS: December 22, 2009</b>
Direct lines of communication among structural steel team	Team member relationships	1:09:03.6: S: In terms of communication versus these different models - If not all of the parties are willing to openly communicate then it doesn't really matter what type of model you have. I think a lot depends on the players you have involved. Their experience, and their willingness to communicate with each other is going to do a lot to bring forward any issues that you have and get the project moving in the right direction regardless of what type of contractual obligation you have.
Early involvement of the erector and fabricator in the steel design process	Early involvement of fabricator and erector	1:43:37.9: S: I think the early involvement is great, but I think the one key thing we touched on briefly is it doesn't matter how early you get your parties on board if it's not the right people within those parties.

<b>Recommendation</b>	<b>Discussion Topics</b>	<b>Engineering Manager, KL&amp;A: December 22, 2009</b>
Direct lines of communication among structural steel team	Team member relationships	41:03.3: S: So we did have some integration along the communication because we all know one another's work through various projects. We have the relationships. There was an integrated communication process even though there weren't integrated contractual lines.
	Integrated Steel Delivery method	1:04:44.9: S: I like the OSP model. I think it's more integrated.
Early involvement of the erector and fabricator in the steel design process	Early involvement of fabricator and erector	41:03.3: S: When we did have cross-communication and integration between the different trades, with all the timing that happens with the typical delivery method that follows the contractual relationships you have right there (referring to flow chart) had happened after CDs had been issued.
	Early involvement of all key stakeholders	1:04:44.9: S: I think it [OSP model] provides earlier involvement between the engineer and the rest of the construction team because they are financially committed to be involved.
Appropriate technology	Interoperability issues	1:53:52.0: S: I'm not sure how much experience there's been in sharing models across lines of scope of work.

Recommendation	Discussion Topics	Principal Engineer, KL&A: December 22, 2009
Direct lines of communication among structural steel team	Design Build versus Design-Bid-Build	43:20.1: B: If you're talking about the overall Design-Build, it is way, way ahead of the traditional Design-Bid-Build in terms of communication.
	Communicating despite contractual arrangements	38:07.7: B: The fact is, you'd have to draw a whole bunch of dotted lines [on the contractual arrangement flow chart] from the design team to the detailer to the erector to the fabricator and to the contractor because during design we talked with all five of those entities completely outside of the contractual arrangement because that's how we work.
	Communication hierarchy	43:45.4: B: Even though there are dotted lines going to all these different parties, we all understand that in this particular case Paxton-Vierling had responsibility for the structural steel erection and detailing and construction. When issues come up where that's important, we absolutely make sure that everything follows the right contractual channel. Josie: So if there's a problem that runs through here (points to steel detailer box on flow chart) it has to go to the fabricator which goes to the contractor which goes to the architect and back down to the designer and then it has to go back through all those channels to get here (back to steel detailer box on flow chart)? B: Yes
	Integrated Steel Delivery method	45:12.2: Helene: Is there a way to draw a line between the design team and the detailer so that it can all be under the same entity? B: Well, we do projects where KL&A is the steel subcontractor...OSP was done with this exact same team actually.
	Benefits of open lines of communication	1:05:59.6: B: I think there's no question that in any situation better communication results in more efficiency, which can translate into sustainability as well.  1:40:53.4: B: That lower dollar is a direct relation to efficiency, in my opinion, and sustainability and all those other things. Dollars do equal sustainability in this regard
Early involvement of the erector and fabricator in the steel design process	Early involvement of fabricator and erector	1:47:04.6: B: The other part of early involvement is it's very difficult to have a highly sustainable building without this early involvement piece that we're taking all the way down to fabricator, erector, and builder.
	Drop in knowledge	1:47:04.6: B: The last point would be this idea of loss of knowledge about the project results in enormous inefficiencies.

	Trust impediment	<p>1:06:13.0: B: The impediments right now to a more direct transformation is these issues of tradition and the fact that the design and construction industry is a fairly slow changing industry, and then the issue of trust, which is critical to these communication issues.</p> <p>1:41:58.3: B: The main impediment to this early involvement is trust. And it's not does the GC trust LPR? It mainly has to do with the delivery method.</p>
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