### Summary for CIFE Seed Proposals for Academic Year 2015-16

<table>
<thead>
<tr>
<th>Proposal number:</th>
<th>2015-08</th>
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<tbody>
<tr>
<td>Proposal title:</td>
<td>Leveraging Supply Chain Data for Structural Steel Design</td>
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</table>
| Principal investigator(s)\(^1\) and department(s): | Professor Martin Fischer  
Department of Civil and Environmental Engineering |
| Research staff:          | Forest Flager, Henry Hamamji, Pratyush Havelia |
| Total funds requested:   | $ 59,776 |
| Project URL for continuation proposals | http://web.stanford.edu/~forest/ |
| Project objectives addressed by proposal\(^2\) | Buildable, Sustainable |
| Expected time horizon    | 2 to 5 years |
| Type of innovation       | Breakthrough |

**Abstract (up to 150 words)**

**The problem:** Engineers design steel structures today with limited knowledge of how their decisions impact project cost, schedule and environmental impact.

**The proposed solution:** Enable engineers to leverage supply chain information early in the design process to support more informed design decisions.

**The proposed research approach:** Work with steel supply chain organizations, specifically mills, fabricators and erectors, to develop methods to provide automated cost, schedule and environmental impact estimates based on schematic design information provided by the engineer. We will develop model-based visualization methods and computational structural optimization methods that will leverage this data for design decision support. We will test the effectiveness of the model-based visualization methods using design charrettes and the structural optimization methods using case study projects in collaboration with our industry practitioners.

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\(^1\) The PI(s) must be academic council member(s) at Stanford.

\(^2\) For this and the next points, delete the answers that don’t apply to your proposal.
1. Motivating Problem

Engineers design steel structures today with limited knowledge of how their decisions impact project cost, schedule and environmental impact. Conventional practice during the schematic and design development phases of the project is to estimate cost based on the total weight of the steel structure. However, weight is not always an accurate surrogate for the total cost of a steel structure (Nanakorn and Meesomklin 2001). Raw material only accounts for about one third of the final cost of a steel structure in place. Fabrication and erection account for the majority of the total cost as indicated in Figure 1. These costs depend on structural detailing, site conditions and other factors that do not scale linearly with structural weight. In addition, data obtained from steel mills indicates that material cost depends not only on amount of steel required, but also on the type (e.g., tube, wide flange) and size of cross sections utilized. The relative cost of this material varies based on current production costs, inventory, and other market conditions.

![Figure 1: Cost breakdown for structural steel systems in buildings. Conventional practice is to estimate cost based only on the quantity of raw material which is frequently not representative of the total cost.](image)

A limitation of conventional practice is that engineers do not have access to fabrication and erection cost information during the schematic and design development phases of the project when they are making key design decisions that largely determine the total cost of the structure including the type of lateral system, the framing plan layout and preliminary member sizing. A case example that illustrates this point is shown in Figure 2. The Figure depicts two design options for a moment frame lateral system for a ten story office building in southern California that was designed by a leading engineering firm in 2011: Option 1 has variable beam and column dimensions to minimize material use. Option 2 has consistent beam and column sizes to simplify fabrication and erection: it utilizes 5% more material, but the total cost is 11% less than Option 1 due to reduced fabrication and erection costs as described in Table 1. The engineer designed Option 1 assuming this would be a more economical design since in required less material. The fabricator did not get involved in the project until detailed design of the building had been completed and recommended Option 2 as a value engineering proposal which would have saved approximately $500k USD. However, it would have required significant redesign which was not possible at that stage in the project since the steel had already been ordered.
Table 1: Case example describing steel weight and cost breakdown for a 10-story steel moment frame. Option 2 utilizes less material, but costs 11% more compared to Option 2 due to significantly higher fabrication and erection costs.

The goal of the proposed is to enable designers to leverage supply chain information on steel cost and availability during the schematic and design development phases of the project when they are making key design decisions that largely determine the total cost of the structure.

Theoretical and Practical Points of Departure

Structural Optimization: There has been significant past research into structural steel optimization. These optimization methodologies include the application of both deterministic and heuristic approaches and have been proved to reduce the overall weight of steel by considerable amounts (Flager, Adya, Haymaker, Fischer, 2011; Papadrakakis, Lagaros, Plevris, 2005; Adeli, Sarma, 2006). However, as discussed above, weight is not always an accurate surrogate for the total cost of a steel structure. Very few researchers have attempted to develop an objective function for the optimization that includes fabrication and erection costs in addition to material costs. In these cases, the solutions are restricted to academic examples and are not scalable to the industry level. Consensus from existing literature on cost optimization theories is that the holistic cost optimization rather than weight optimization alone can result in additional savings between 7%-26% of the total cost of the steel structure.

Model-Based Visualization: Visualization techniques have been applied in construction to help make better construction management decisions by improving material workflow and supply chain management. This is implemented by tagging objects with barcodes to track the status of construction items which is then represented in real-time by colored 3D model visualization schemes (DPR and CIFE, 2009). These tools have provided general contractors the ability to make
better decisions by forecasting potential outcomes and providing real-time information feedback through sharing and management of information. Methods to visualize supply chain data in the context of the Building Information Model (BIM) to help support design decisions have not yet been implemented.

**Building Information Modeling (BIM):** Recent BIM developments enable this project two ways: firstly, numerous design software and schemas have emerged to sufficiently document projects, and secondly, BIM has become a fully integrated into professional practice and contracts such that buildings are actively being documented with data-rich models. Our project leverages the particular member details in these models to provide more accurate cost information.

**Internet Access and Cloud Infrastructure:** Commercial broadband penetration has grown to 72% of businesses, and this connectivity enables designers and fabricators to exchange detailed models continuously throughout the design process in matters of seconds, rather than several minutes or hours in previous decades. An immediate feedback loop enables our tool aims to help designers make better decisions as they are designing, not after they have finished. A component of this project is a secure platform configured by members of the supply chain. Cloud computing drastically lowers the barrier to hosting these services, allowing for more iteration and experimentation.

**steelXML:** A schema being developed by the American Institute of Steel Construction (AISC) and the Digital Building Laboratory (DBL) at Georgia Institute of Technology. It is intended to facilitate communication between steel material buyers and mills by enabling the mills to publish online current information about the cost and availability of their inventory. However, this schema does not support the inclusion of fabrication and erection cost data.

**Research Methods and Work Plan**

The goal of the project is to enable designers to leverage supply chain information to make better decisions early in the design process. We are working with industry partners (structural steel mills, fabricators, erectors and design engineers) to develop methods to provide automated cost, schedule and environmental impact estimate based on schematic design information. The system architecture for the proposed research is shown in Figure 3.
Figure 3: System architecture for proposed research which provides automated steel cost and availability data in the context of the Building Information Model (BIM).

In particular, the research team is developing the following methods / technology:

- **Model-based visualization**: to enable practitioners to visualize the relative cost, availability and embodied carbon of individual steel members and connections in the context of the Building Information Model (BIM)

- **Structural optimization**: computational algorithms to help designers systematically search through large numbers of design alternatives to quantitatively evaluate trade-offs between design objectives (e.g., cost vs. availability, cost vs. carbon) and to identify structural design solutions that best meet the project objectives

The system architecture for the technology develop technology described above will be designed to provide quick and accurate information to designers based on current supplier data. The research team will test the effectiveness of model-based visualization methods using design charrettes and the structural optimization methods using case study projects in collaboration with industry practitioners as described in more detail below:

- **Design Charrette(s)**: Practitioners will be divided in two groups and given the same simple design problem. One group will have access to the tools developed by the research team and the other will utilize traditional design methods. The research team will measure and compare the efficiency and effectiveness of each design process in terms of time required to generate and analyze design alternatives, number of alternatives analyzed and the alternative performance of the a with respect to the stated design objectives and constraints.

- **Case Studies**: We will apply the structural optimization methods developed to a current or past project designed by our industry partners. The research team will compare the optimization process to the conventional design process in terms of the metrics described above.
Expected Results: Findings, Contributions, and Impact on Practice

The proposed research will provide architects and engineers with real-time feedback on how their structural design decisions impact the project cost, schedule and environmental impact. The research team expects that this information will enable designers to make better decisions and that it will demonstrate the value of improving vertical integration of project information in AEC industry. Fundamentally improving the design process in this way will promote design innovation by making it easier to analyze and iteratively improve new design concepts based on current and accurate data provided by the product supply chain. Ultimately, this will result in higher quality and more economical buildings for the public.

If we are successful in leveraging supply chain information to support better design decision making in the structural steel domain, our model of vertical integration of information can also be applied to other major building systems and products (e.g., reinforced concrete structures, HVAC systems, etc.).

Industry Involvement

This project overlaps with several industries: software development and structural engineering as well as steel production, fabrication and erection. Consumers of the tool, such as architects, engineers, and contractors, will use it to price their design models. Producers for the tool, such as steel mills, steel fabricators, and steel erectors, will supply pricing information and their costing algorithms. Industry contacts that have been involved in the project to date are summarized below. The research team invites CIFE member companies from each of the industries listed below to participate in this research project.

<table>
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<tr>
<th>INDUSTRY</th>
<th>ORGANIZATION(S)</th>
<th>CONTRIBUTION(S)</th>
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<tbody>
<tr>
<td>Software</td>
<td>Autodesk</td>
<td>Web front end development; secure API backend development; product integration.</td>
</tr>
<tr>
<td>Structural Engineering</td>
<td>Rutherford + Chekene, SOM</td>
<td>Prior steel models and pricing data set; beta software user.</td>
</tr>
<tr>
<td>Steel Fabrication</td>
<td>Herrick Corporation</td>
<td>Cost modeling algorithms; fabrication cost input.</td>
</tr>
<tr>
<td>Steel Erection / Construction</td>
<td>Herrick Corporation, Micon Construction</td>
<td>Steel erection cost input; Beta software user.</td>
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*Table 2: Organizations currently involved in the proposed research and their respective contributions.*
Research Milestones and Risks

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<tr>
<th>MILESTONE</th>
<th>COMPLETION DATE</th>
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<tbody>
<tr>
<td>1. Define system architecture and component information requirements</td>
<td>June, 2015</td>
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<tr>
<td>2. Populate material, fabrication and erection cost model</td>
<td>August, 2015</td>
</tr>
<tr>
<td>3. Model-Based Visualization Design Charrette</td>
<td>November, 2015</td>
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<tr>
<td>5. Case Study #2: Structural Optimization</td>
<td>March, 2016</td>
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Table 3: Research milestones

The major risks to the project are as follows:

- Willingness of project stakeholder to share confidential information on the system based on confidence that this information will remain secure.
- Reliance on Autodesk to provide web front end development, secure API backend development and product integration
- Reliance on industry partners to participate in design charrettes and case study validation exercises.

Next Steps
Potential sources of continuation funding include:

- American Institute of Steel Construction (AISC)
- Autodesk
- National Science Foundation

References