INFLUENCE OF OFFSHORE OUTSOURCED STRUCTURAL DESIGN PROCESSES ON CONSTRUCTION OPERATIONS

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ABSTRACT: This manuscript reports the findings of a research endeavor that has characterized the process to deliver detailed workshop and erection design documents for steel structures when outsourced to offshore design service providers, and has assessed the influence of these design processes on construction operations. The study has considered all aspects (organizational, transactional, and resource-based) of the structural design process among the key participants, i.e. owner, contractor, designer, and manufacturer. However, only the findings at the interface between design and construction are presented in this manuscript due to space constraints. An exploratory case study methodology was undertaken and ethnographic data from US client and Indian vendor companies was collected. As part of this ethnographic data collection, interview data comprising 23,000 words was coded to identify the constructs that characterize offshore outsourced structural design processes. Several shortcomings currently characterize these design processes. For instance, the inefficient use of design technologies penalizes the communication of design information between the involved participants. These inefficiencies frequently result in undetected clashes between the structural members and facility/building components (such as building services) that need to be identified and resolved at the job site at the expense of increased construction costs and extended completion times. In addition, the inefficient exchange of design information among participants result in excessive and time consuming design revisions that frequently extend design and construction schedules. To this date, past research efforts have investigated primary (architectural) offshore outsourced design processes but have, for the most part, omitted offshore outsourced structural design processes.

***Keywords**: Design, Construction, Constructability, Outsourcing, Offshoring, Globalization, Technology*

1. INTRODUCTION

Growing project complexities and recent technological breakthroughs have enabled Architectural, Engineering, and Construction (AEC) firms to increasingly subdivide complex design tasks and to separately contract them to specialized trade vendors at offshore locations. Thus, an increasing volume of complex design services are actually being outsourced to specialized vendors [1] [2] [3]. For instance, in the US complex design services account for 75% of all activities outsourced by the AEC industry [3].

Among these design services, this study targets the understudied downstream structural steel engineering services (SES) when outsourced to offshore design service providers. SES encompasses secondary design (e.g., connection design), tertiary design (design of staircases, handrails etc), and ultimately the production of workshop and erection drawings. Thus, downstream design services are a crucial step to guide the shop personnel to produce the structural steel components, the erection crews during installation activities, and hence exert a high level of influence in the execution of the capital project.

According to the National Association of Software and Service Companies (NASSCOM), AEC firms have overtaken manufacturing firms in offshoring engineering services to India [2]. Indeed, according to a different source, 44% of US firms are already offshoring their engineering functions [2]. Even though offshore outsourcing of design services brings upfront reduced costs,

disadvantages have also been reported. Downstream engineering services are one of the most difficult services to offshore [2]. Hence, the quality of the design product frequently decreases in such offshore collaborations. Indeed, the offshoring of design services not only aggravates existing project delivery complexities, but also adds newer ones [4] [5], such as laborious exchanges of design information and design errors. Furthermore, the reduced quality of detailing and the time lost in communication exchanges are both replicated in time losses by others upstream project participants, such as contractor organizations.

Another important concern is associated with technology interoperability. While web-based project management systems (WPMS)—file transfer protocol (FTP) mechanisms, servers, and building information models (BIM)— can enable the storage and exchange of project-related information between virtual and geographically dispersed teams [6] [7], offshore vendors seem to still rely on unsophisticated design tools [8] [9], such as two dimensional building computer aided design (CAD) products. Such poor technology implementation limits efficiency of collaboration between project participants [10]. Thus, it has been stated that it is necessary to identify through empirical research methods various causes that limit technology implementation in offshore networks [6]. Past researchers have largely focused their studies on the investigation of primary design services, typically those in which US clients collaborate with offshore virtual counterparts to carry out primary design. Only a minute number of studies exist on downstream design services, which have been restricted to interactions between owners, fabricators, and engineers, and thus neglecting the role of offshore structural detailers.

2. METHODOLOGY

This study characterizes the process to deliver workshop and erection drawings for steel structures when outsourced to offshore design service providers, and assesses the influence of these processes on construction operations. To fulfill these research objectives, an exploratory case study research methodology [11] [12] [13] was undertaken. This methodology yielded to the definitions of the constructs that define SES collaborations with implications in design technologies, constructability, electronic data interchange, multicultural, and organizational issues, among others. However, this manuscript only presents the findings at the interface of design and construction due to space constraints. Thus, the constructs discussed in this paper are: 1) inefficient design information exchange; 2) inefficient use of design technologies and 3) lack of constructability focus. In the following sections of the paper we discuss our findings by first characterizing the offshore SES and the overall design processes, and then elaborating on these constructs.

3. STRUCTURAL ENGINEEING SERVICES

Two types of collaboration structures among the key participants in the design processes were observed. The design-build type collaboration involved Engineering Procurement and Construction (EPC) firms that shared part of their design process with offshore subsidiaries. The most prevalent type of collaboration, though, was the traditional design-bid-build. In such collaborations, architects, general contractors, designers, and trade subcontractors (such as steel fabricators) outsourced downstream design services to offshore firms.

3. DESIGN PROCESS

Figure 1 illustrates the design process. Primary design, which includes core structural and architectural design, is a collaborative effort between owner, architect, discipline engineers, and sometimes the general contractor. Based on the primary design documents, the US clients outsourced secondary and tertiary design, and structural detailing to SES vendors offshore. Basically, these vendors are entrusted with the delivery of production and erection drawings that govern the subsequent fabrication and construction activities. SES may be initiated at different stages during the design process, depending on the type of collaboration structure. US clients usually choose vendors based upon factors such as bid competitiveness, market reputation, and past relationships. FTP tools are used by clients to exchange design-related information with the

design firms, information such as contract documents, architectural and structural drawings (primary design information), specifications, connection design prototypes, and sample drawings. Vendors detail 3D models utilizing the primary design input (typically in 2D). During the design process, design questions and clarifications need to be raised by the vendor and formally requested to the client by initiating a Requests For Information (RFI) transaction.

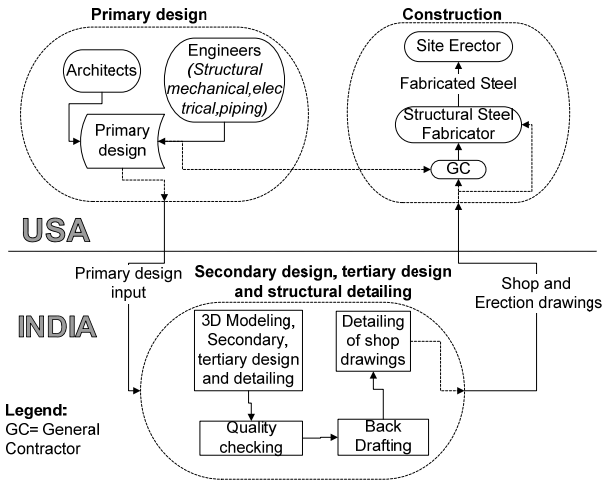

Fig. 1 Design Process

Once the 3D model is completed by the vendor, individual steel members are detailed according to client's requirements in terms of connection, manufacturing, style, and editing standards. Engineers contracted by the client review the drawing documents and the model for quality purposes and report the corrective actions that need to be undertaken by the vendor. Once corrected, the approved design documents are the basis for both the fabrication of the steel components and their installation.

4. INEFFICIENT DESIGN INFORMATION EXCHANGE

Offshore SES collaborations exhibit shortcomings in relation to the exchange of design information between vendors, clients, owners, and the other key participants in the design process. Some of these shortcomings are discussed below.

Incomplete drawings and design revisions: Vendors typically start the secondary and tertiary design work based on scanned images of design drawings that have been previously supplied at initial bidding stages. These scanned drawings are not only incomplete but, frequently, the information contained in them is barely visible. The use of magnifying lenses or zoomed views through the computer to get a better understanding of the design information contained in the scanned copies of the drawings is a normal practice by the engineers in vendor firms. Once the design process is initiated, multiple design revisions and design change orders are of common practice. Vendors expressed that, on average, 5 to 6 sets of revised design drawings are received during the design of any given project. Each time a revision or change order occurs SES vendors are bound to perform a thorough study of the revised drawings to track down and accommodate all the relevant revisions. For example, a commercial project that started with a revision bulletin #8 of design documents was subsequently re-revised until bulletin # 23 in a period of just 6 months. Design revisions, and change orders alike, not only interrupt vendors' work flow, but also add to the design completion time and cost. They can also negatively affect the quality of the installation and manufacturing drawings that is to guide the fabrication and construction processes.

Inefficient RFI transactions: In SES networks and as a consequence of incomplete drawings and poor information supply, vendors typically raise a large number of RFIs. The RFI process is typically cumbersome (for instance, many intermediate parties screen the communications between vendors and RFI respondents) and results in mismatched RFI communications and late responses. First, mismatched RFI communications not only complicate the design process but can negatively affect construction operations. Each RFI has a unique tag number. However, due to lack of systematic standardization in the AEC project networks, the tag number of an RFI inquiry by a vendor firm is frequently different from the tag number of the equivalent RFI response by the client, owner, or consultant respondent firm. Due to the vast amount (typically in the hundreds) of RFIs that are initiated in a single project, the design

participants lose considerable time in trying to rightfully track the RFI responses and match them with the original RFI inquiry. Losing track of the crucial RFIs have been observed to lead to wrong detailing and fabrication information, which have shown to have serious negative effects on installation processes. Second, late RFI responses negatively affect the design process. Ideally, "*the ideal time to answer an RFI for the client is about 24 hrs to 48 hrs*" according to the National Institute of Steel Detailing (NISD). RFIs responses in SES networks are, on average, delayed much beyond the recommended timeline. For instance, we documented RFI responses that were received by vendor firms three months after the inquiry had been generated. The design schedule and project completion dates need to be delayed since the finalization of the fabrication drawings needs to be postponed. The fact that many RFIs need to be re-submitted due to miscommunications between vendors and respondents add to the problem generated by late responses.

5. INEFFICIENT USE OF DESIGN TECHNOLOGIES

Offshore SES collaborations exhibit shortcomings in relation to the use of technologies by vendor and client companies alike. Some of these shortcomings are discussed below.

Obsolete data interchange: Technology interoperability is poor among offshore SES networks. As shown in Figure 2, architects, contractors, designers, and trade contractors during the primary design process tend to share the design information consolidated in a Building Information Model (BIM). However, clients (commonly owners, general contractors, or fabricators) do not share BIM with offshore SES vendors or any other offshore engineering service provider. At most, they share either a vaguely detailed structural steel 3D model extracted from the consolidated BIM or just the Steel Detailing Neutral Files (SDNF), which need to be imported into a CAD software tool to generate the primitive structural steel 3D model. Unfortunately, these SDNF-generated steel models are seldom accurate and need "*considerable repair work*". Vendors do not want to take risks by importing the information in the neutral files. Therefore, vendors recreate the whole structural steel 3D model using 2D design information. BIM information is not shared in order to preserve confidentiality of the standards, styles, practices, and know-how information contained in the BIM model.

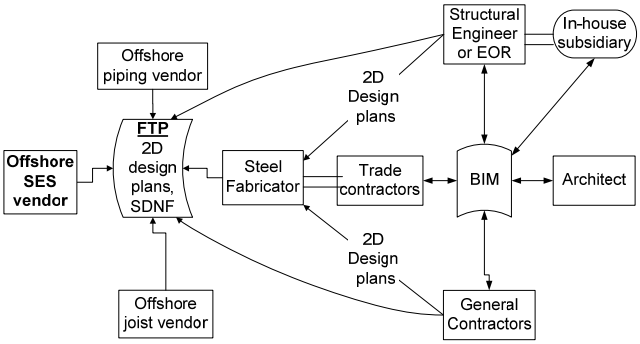

Fig. 2 Technology Interoperability

Detailing templates: Steel detailing templates files can be created to predefine the standards, styles, specifications and layout settings of workshop drawings. Despite the fact that steel detailing template files can potentially save considerable detailing design time, clients do not typically share template files with the vendor firms. As a result, SES detailers spend 30% of their design time for a project editing the workshop drawings for thousands of individual steel components.

Outdated software tools: Due to the differences in purchasing power between the US and India, vendor firms cannot typically afford purchasing the most updated versions of detailing software tools. As an alternative, they chose to use less expensive but outdated versions of detailing software packages. For example, one vendor firm used an outdated version of SDS that required the detailers to manipulate three mouse buttons for model screen navigation purposes –as opposed to the easy mouse wheel scroll navigation of the current software versions.

6. LACK OF CONSTRUCTABILITY FOCUS

In pursuit of immediate profit, both client and vendor firms did not appreciate the need to ensure the constructability of

the designed steel structures. Even though it is evident that timely checks for clashes between different trade models is essential to identify constructability issues [14], offshore SES vendors do not check for model clashes with other trade disciplines because of a lack of access to other trade models or to the consolidated BIM model. A client representative stated this problem with the following example: *"detailers only have the steel model and not the piping model; therefore, they are not able to make appropriate cutouts in steel wherever there are pipe shoes or pipe trunnions."* Eventually, if the primary designer also fails to notice the clashes in the complex consolidated model, there are expensive erection conflicts on the field. Miscellaneous steel like, handrail, gratings, gussets, connection angles, etc. need to be reworked on the site at the costs of keeping erection crews and expensive equipment assets idle. India's lack of steel industry further causes constructability issues from the vendor side. In addition to this lack of steel expertise, Indian offshore vendors' inexperience with US industry standards related to manufacturing, shipping, transportation, or installation further aggravates the lack of constructability focus. To compensate for their inexperience, vendors rely on their mental visualization skills to think meticulously in terms of steel erection and assembling. Realizing the importance of visualization, fine visualization skills are considered as a key recruiting parameter when vendor firms decide to hire new engineers.

7. CONCLUSIONS

This manuscript reports the partial findings of a research endeavor that has characterized the process to deliver workshop and erection drawings for steel structures when outsourced to offshore design service providers, and assessed the influence of such design processes on construction operations. Three constructs summarized the key findings presented in this manuscript. First, offshore SES networks are characterized by inefficient exchanges of design information, in terms of: 1) inadequate design information supply by clients, 2) screening of communications among project participants, and 3) inefficient RFI transactions caused by a large number RFIs initiated by the vendors and the unsatisfactory responses generated by the client or other respondents. Second, an inefficient use of design technologies permeates offshore outsourced SES collaborations. Obsolete methods of data interchange, like the use of non-interoperable design information among client and vendor firms and the null utilization of design templates to streamline the production of workshop drawings burdens the design process. In addition, vendor firms tend to use inexpensive but outdated design tools that further burden and extend the duration of the design process. Third, there is a lack of constructability focus both among client and vendor organizations. The Indian SES vendors' lack of both steel construction expertise and knowledge of the US industry standards are combined with a lack of constructability focus by client firms that frequently result in severe constructability problems. Constructability issues in the design documents need to be identified and resolved at the project site by erection crews at the expense of extended schedules and increased costs. Overall, the findings of this study contribute to the understanding of offshore outsourced structural steel design processes.

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