CONTRIBUTION OF SPECIALTY CONTRACTOR KNOWLEDGE TO EARLY DESIGN

Gil, N.[1], Tommelein, I.D.[2], Kirkendall, R.L.[3], and Ballard, G.[4]

ABSTRACT

This paper discusses what knowledge specialty contractors may contribute to the early design of architecture, engineering, and construction (AEC) products. In current practice in the United States, specialty contractors are seldom involved in the early design effort, but their early involvement is increasing. The paper reports on research that focused on the processes for designing and building semiconductor facilities. The research consisted of conducting a series of one-to-one interviews with experienced practitioners, ranging from labour managers to lead designers and owner representatives. The aim was to unveil what kinds of knowledge specialty contractor may contribute to early design in order to improve process efficiency and product quality. We catagorize this knowledge and provide examples that stem from current practice or that present opportunities for implementation. We discuss reasons why specialty contractor knowledge may be ignored. Changes taking place in the AEC industry nevertheless suggest that organisations are creating conditions to increase the interaction between designers and specialty contractors. Such interactions may help AEC organisations retain and share the knowledge of individuals as well as develop new knowledge and thereby increase their competitive advantage.

KEY WORDS

Specialty contractor, knowledge, lean construction, early design, concurrent engineering, product development, process improvement

INTRODUCTION

Architecture, engineering, and construction (AEC) projects comprise complex design and building processes that lead to the delivery of a facility. They involve at least a design (or design-build) firm, a project manager or general contractor, and an array of specialty

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[1] PhD Candidate, Constr. Engrg. & Mgmt. Program, Civil & Envir. Engrg. Dept., 215 McLaughlin Hall, U.C. Berkeley, CA 94720-1712, USA, ngil@uclink4.berkeley.edu, http://www.ce.berkeley.edu/~nunogil/

[2] Associate Prof., Constr. Engrg. & Mgmt. Program, Civil & Envir. Engrg. Dept., 215 McLaughlin Hall, U.C. Berkeley, CA 94720-1712 , USA, tommelein@ce.berkeley.edu, http://www.ce.berkeley.edu/~tommelein/

[3] Sr. Interior Designer, Industrial Design Corporation, 2020 S.W. Fourth Avenue, 3rd Floor, Portland, OR 97201, USA, robert.kirkendall@idc-ch2m.com

[4] Lecturer, Constr. Engrg. & Mgmt. Program, Civil & Envir. Engrg. Dept., 215, McLaughlin Hall, U.C. Berkeley, CA 94720-1712, USA, and Research Director, Lean Construction Institute, 4536 Fieldbrook Road, Oakland, CA 94619, ballard@ce.berkeley.edu

contractors. Design firms typically are in charge of most of the design development process. The general contractor may execute some construction work, such as the erection of the concrete or steel structure. In turn, specialty contractors most often competitively bid on different parts of the remaining construction work. Their work is segmented according to the different specialities, such as mechanical, electrical, and process piping. Many projects today engage the services of twenty if not more specialty contractors.

How to effectively co-ordinate the work of specialty contractors in AEC projects has for long been an industry concern (Crichton 1966). The work of specialty contractors has evolved from artisan-ship to sophisticated assembly of components (Gray and Flanagan 1989, Bennett and Ferry 1990). Their work, typically done on-site, has progressively shifted to include more off-site tasks (such as creating detailed fabrication and installation drawings, selecting vendors, procuring and expediting delivery of materials and equipment, fabricating components), and, besides building, now also includes starting-up and maintaining building systems (Tommelein and Ballard 1997).

In current practice in the United States specialty contractors are seldom involved in early design. Design-build organisations primarily select specialty contractors once designers have produced a set of drawings and specifications defining the AEC product. Inefficiencies during construction then result from lack of interaction between contractors and designers.

Research on the co-ordination of specialty contractors has focused on competitive bidding and its detrimental impact on project effectiveness. Uher (1991) and Hinze and Tracey (1994), for instance, critique the AEC industry’s persistent use of harsh contractual agreements between specialty- and general contractors. Pietroforte (1997) stresses the mismatch between sub-contracting practices vs. the actual project working relationships that exist between contractors and specialty contractors.

In contrast, other industries have progressed towards more involvement of suppliers in product development and manufacturing. In organisations that have adopted lean manufacturing practices, suppliers work closely together with manufacturers in order to streamline the production processes (Womack et al. 1990, Clark and Fujimoto 1991, Ward et al. 1995). They share information on their production systems in order to reduce inventories, perform just-in-time parts delivery, increase reliability of supply lead times, and cut costs. To achieve this, manufacturers have changed their practices, e.g., they may move their organisation’s employees to work at suppliers’ installations, and create conditions so that supplier employees can work in their assembly plants in order to ease joint development.

In addition, manufacturers have established incentives for suppliers to get involved earlier in design: they have increased the total order quantity (though probably reduced the delivery quantity) and committed to long term contracts. Suppliers’ early involvement aims to (1) avoid conflicts in the assembly stage that stem from lack of understanding between suppliers and manufacturers, (2) create conditions to stimulate innovation, (3) reduce meaningless changes in product development and manufacturing, (4) create conditions to start manufacturing without complete product information while avoiding overly conservative assumptions, (5) increase trust and mutual commitment among parties, (6) make upstream-downstream-friendly solutions, and (7) make it possible to postpone decisions in design without sacrificing overall development and implementation time.

Similarly, in the computer industry, manufacturers work together with suppliers in early design to leverage available technology and achieve gains in process efficiency (Iansiti 1995). Because market conditions are unpredictable and technology evolves rapidly, manufacturers overlap the concept development and the implementation stages to gain speed.

Figure 1 (a) illustrates a traditional model for product development in manufacturing. It is akin to design-bid-build contracting in the AEC industry. Contrary to current practice in fast-track AEC projects, in which designs are piecemeal developed and released to construction, Figure 1 (b) illustrates that the more advanced manufacturers postpone the date when they freeze the design concept in order to gain flexibility to accommodate late changes.

Given these observations, we wondered to what extent these new practices regarding supplier involvement would be applicable to the AEC industry. Assuming that contractors in AEC systems are the equivalent of suppliers in manufacturing, the key question of our research is: What knowledge can these suppliers bring to the table?

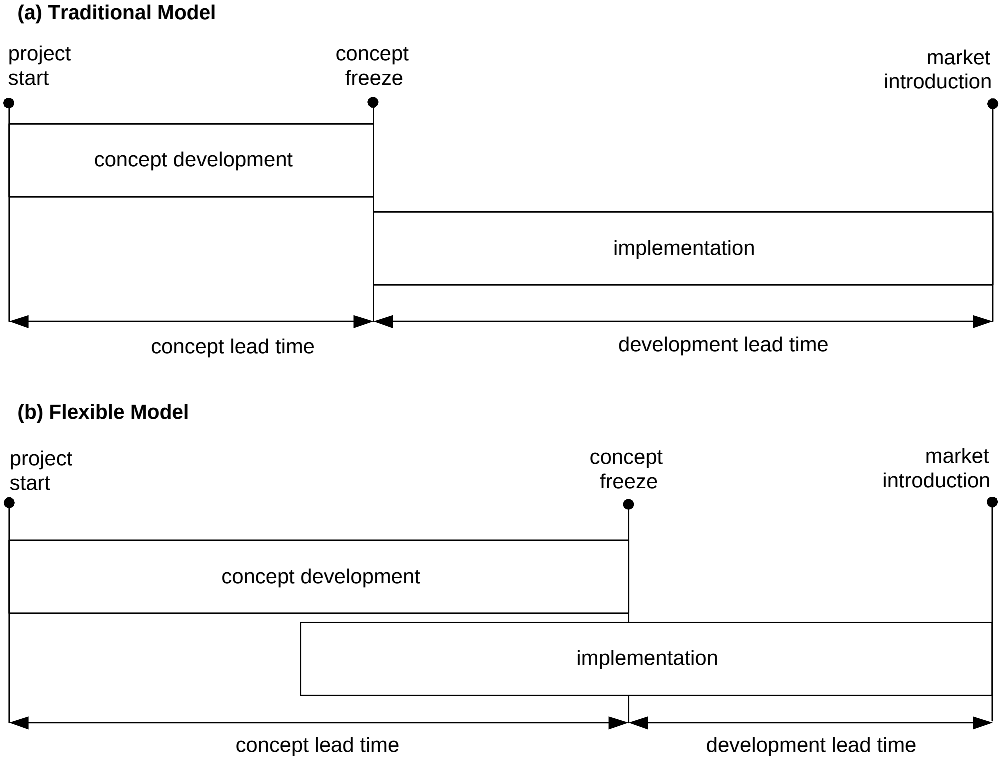

Figure 1 Two Models of Effective Product Development (Iansiti 1995)

RESEARCH APPROACH

Our research project has focused on developing an understanding of the value specialty contractor knowledge can bring to early design. We chose the design and building of semiconductor facilities as a research setting. These high-tech facilities are technologically complex and have to be built fast and economically, in intense conditions of uncertainty regarding design criteria and scope.

The research consisted of three phases. Since November 1998, we have been interviewing people at a design-build firm, then people at specialty contracting firms, and finally people at owner organisations. All were experienced in the design and building of semiconductor facilities. The interviews lasted approximately one to two hours. Frequently, we carried out follow-up interviews. No written questionnaires were used. All interviews were audio taped except for those done over the telephone.

In the first phase, we interviewed 18 lead designers, design managers, and construction managers, who work at Industrial Design Corporation (IDC), in Portland, Oregon. IDC is a leading-edge design-construction firm, with a wealth of expertise in high-tech facilities. The total number of interviews approximately doubled with follow-up interviews. We questioned interviewees regarding the decisions they make in early design, the information they typically have on hand and what they wished they knew before making decisions, and the hand-offs of information between design specialties. In the second phase, we interviewed 12 people who worked for specialty contractors, ranging from labour manager to vice-president. The interviews aimed at better understanding the knowledge held by specialty contractors and its contribution to early design. We limited the interview process to the mechanical, electrical, and piping (MEP) trade contractors. In the third phase, we interviewed 7 people who worked for owner organisations. The interviews aimed at better understanding the uncertainties that plague the definition of design criteria and project scope of semiconductor facilities. We also probed interviewees into innovative practices that could add value to the design and building processes.

AVAILABILITY OF SPECIALTY CONTRACTOR KNOWLEDGE

The contributions of specialty contractor knowledge to early design can be multiple. We categorised these contributions in four categories.

ABILITY TO DEVELOP CREATIVE SOLUTIONS

Specialty contractor knowledge can bring creative solutions to early design, which designers may not necessarily be aware of. On one hand, part of the specialty contractors' creativity results from their continuous involvement in projects of different owners and designed by different design firms. Such diversification and rotation of work exposes specialty contractors to alternative ways of solving design problems and keeps them up to date on technological innovations. On the other hand, their creativity may also result from better knowledge of the constraints affecting the construction process.

Admittedly, early involvement of specialty contractors may also create conditions where contractor-preferred solutions are imposed, thereby reducing the attractiveness of the design to other contractors that might build it. Note, however, that designers face a similar dilemma when contractors do not get involved early, and take on the additional risk of having to redesign solutions when contractors get on board later and identify constructibility problems.

Example1.A: In a semiconductor project, the original design of the air plenum body (the plenum is the space above the false ceiling of a cleanroom; a cleanroom houses the process tools) specified a steel structure to hang from the ceiling. The structure was to be built on site. Once the mechanical specialty contractor was selected based on his bid for the original design, the contractor developed and proposed jointly with the ceiling manufacturer an innovative system to build the plenum body. The system consisted of 560 modules to be fabricated in a shop and then assembled on site. These modules include in a pre-assembled fashion the ventilation ductwork, the light fixtures, and the ceiling grid. The owner accepted the contractor's proposal and the plenum was built accordingly.

The solution has reportedly brought significant savings in labour hours, installation time and cost, and increased safety of installation. However, it led to redesigning the plenum body at a cost to the owner, and stripping off the electrical system that was already installed according to the original design. Savings in cost and time were largely associated with the efficiencies gained in the execution of the modules in the shop and their ease of installation. The performance quality of the solution is apparently higher because of better conditions available in the shop to carry out work, such as welding. The solution has been patented and the owner is presently exploring its applicability to future projects.

Example 1.B: Offsets, rolled offsets, and 45-degree fittings are ways to change the direction of pipe and ductwork. They achieve shorter routings and can potentially lead to savings in terms of materials, labour, number of welds and flanges, fittings, and space. They are also beneficial from a performance standpoint because they restrict flow less. Yet, these alternatives are seldom used during design development. Apparently, their use is less intuitive for design detailers because detailers frequently limit the graphical representation of building systems to two dimensions. In contrast, specialty contractors typically detail three-dimensionally so as to ease the installation process on site and prevent errors during execution, particularly if they expect labourers not to be all equally qualified. As a result, detailers working for specialty contractors have developed a better sense for the use of these alternative routing solutions than design detailers. We have observed an example in a subfab where the piping contractor got involved early in the design and was able to take advantage of alternative routings to a great extent. Such involvement brought savings in terms of shorter routings, labour hours, and materials. Likewise, Kim et al. (1997) and Fisher and Zabelle (1999) report on comparable instances where the early and concurrent use of three-dimensional models by specialty contractors and designers brought significant gains to the design-build process.

KNOWLEDGE OF SPACE NEEDS ASSOCIATED WITH CONSTRUCTION PROCESSES

Because specialty contractors build the design, they have developed a sense for the needs for space during construction. This need should be accounted for in early design in order to ease construction later. Instances of such knowledge concern access paths to bring in equipment and materials, and clearances around routings so people have space to work and move around. Involvement of specialty contractors in early design can prevent designers from developing solutions that are inefficient to build or that simply cannot be built.

Example 2: To install routing lines in the mains and laterals of a semiconductor subfab, piping and mechanical contractors typically follow a sequence of steps. First, they decide on the length of spools to order, according to the space conditions they expect to exist on site when the spools arrive. Once the spools arrive, contractors have to bring them separately into the building. They then slide the spools up into the steel racks where they put them in rows ready to weld. To weld the spools around, they need 2 to 3 feet (1 m) of empty space sideways. Finally, they hoist the routing line into its final position, for which they need vertical clearance between the area where they welded the spools and their final location. If routings are stacked, contractors can install only those on top after they have installed those at the bottom. Unless contractors get involved in the design process, they cannot contribute to the creation of alternative configurations that would add flexibility to the construction process. Since space constraints are seldom known ahead of time, contractors will frequently decide to order the shortest spools in anticipation of not being able to slide longer spools into place. Shorter spools augment the number of field welds, and, as a result, may unnecessarily increase the number of labour hours and time to install.

KNOWLEDGE OF FABRICATION AND CONSTRUCTION CAPABILITIES

The capabilities of specialty contractors are a function of the qualifications of the labour force available at the time of construction, and of the equipment maintained in fabrication shops. Mechanical contractors, for instance, fabricate ductwork in their shops with specific tools. Those tools dictate how they detail a design so they can most effectively fabricate ductwork. Knowledge about labour and equipment availability enables designers to better match early design decisions and production choices with available building capabilities without sacrificing design creativity and quality.

Example 3: Welding stainless steel is a sophisticated operation. Welding on site takes longer than in the shop for multiple reasons, such as safety concerns for people working on top of ladders and the time people spend on mobilising specialised equipment. Contractors estimate, for instance, that it takes approximately 2 hours to weld a 24” (60 cm) stainless steel pipe in the shop and 10 to 12 hours to perform the same welding task on site.

KNOWLEDGE OF SUPPLIER LEAD TIMES AND RELIABILITY

Specialty contractors can contribute in diverse ways to equipment and material selection in early design. Designers may specify by brand what equipment and material contractors have to procure. They may be concerned that contractors might opt for low-quality and low-cost alternatives, if specifications were less precise. Design specifications are, however, not necessarily customised to each project at hand. Once contractors start procurement, the specified items may not be available but alternatives that are acceptable from a performance perspective may not exactly conform to what was specified. Specifications then end up imposing unnecessarily long lead times or lengthy document trails to approve substitutions.

Specialty contractors have a better sense of urgency with regards to procurement of long lead items and of available alternatives because they are on the receiving end. They have gained experience and developed a sense for the reliability of suppliers regarding shipping dates. If they are involved earlier in design, they can inform designers of lead times associated with alternatives. Moreover, contractors can inform designers of supplier reliability and raise awareness for supplier process performance issues, especially when designer selections are based exclusively on product cost. Moreover, specialty contractors frequently maintain the building systems they have installed for a warranty period. They can therefore help designers and owners differentiate between alternative equipment and system designs in terms of performance reliability, and operation and maintenance needs.

Example 4: Knowledge of material lead times is of the essence to guarantee that specialty contractors can follow the most efficient construction sequence. This sequence is defined in part by common sense, which recommends that contractors first install vertical lines, such as vacuum lines that hook up vacuum pumps to process tools, because of their length constraints. Installation should then proceed with drain lines and ductwork because they are gravity-based systems (they have a required slope) and have the biggest diameters (they take up a lot of space). Then, installation of process piping should follow. Finally, electrical cables should be installed as they offer flexibility to move around obstacles in their routing.

This sequence may be violated when lead times affect the readiness of specialty contractors to execute their work. Electrical contractors that are not constrained by long lead items (many electrical commodities are available on a day's notice, although transformers and the like do have long lead times), can promptly start work once space is available. When other trades, such as process piping and mechanical, have lead items on the order of 4 to 6 weeks if not longer (depending on the kinds of spools and fittings needed, and the suppliers and fabricators involved), the start of their work may be delayed. As a result, it happens in practice that electrical contractors start working while other contractors are still waiting for their orders to arrive. Thus, electrical systems end up blocking the access paths other contractors had relied on. When this happens, either electrical systems have to be ripped out and built anew later, or the other contractors have to find alternative ways to execute their work, using, for instance, shorter spools or more convoluted access paths. In situations like this, time delays and additional labour costs are likely to result.

BEYOND AVAILABILITY OF SPECIALTY CONTRACTORS KNOWLEDGE

Not all available specialty contractor knowledge has made it into practice. In current practice, design-build organisations typically bring together design firms and general contractors but leave out numerous—if not all—specialty contractors. Some of the aforementioned examples therefore remain only potential contributions to early design. Only by involving specialty contractors earlier, will design-build organisations be creating conditions to leverage their knowledge. Naturally, such early involvement implies that design-build organisations should select specialty contractors based on criteria other than competitive bids on completed contract documents. Doing so, design-build organisations and owners will face other issues, the most relevant of which we discuss next.

COMMUNICATION SYSTEMS

Communication systems are important for people in specialty contracting firms to share knowledge with people in design-build organisations. Communication enables specialty contractors to better understand designers' intents, that is, why designers insist sometimes on building in a way different from what contractors think would be best. Contractors will also have the opportunity to discuss alternatives with designers. For instance, designers frequently complain how difficult it is to communicate in contract documents to specialty contractors their intent regarding empty space they want to leave for future needs. As a result, such space occasionally ends up being invaded during construction.

In addition, communication between specialty contractors and designers can help designers and owners more accurately estimate the cost of design alternatives. In semiconductor projects, early cost estimates frequently turn out later to have been undervalued. Design-build organisations and owners tend to let less realistic estimates proceed during design, even if individuals may be sceptical because costs of changes are not explicitly accounted for. Only when contractors bid the project, will awareness for costs escalations finally become explicit. Owners may then impose new changes in design aimed at bringing costs within the budget. Such changes cause rework and waste time and resources. Greater accuracy in cost estimating would help design-build organisations and owners better rationalise their early design decisions and choices.

We have observed the use of multiple communication mechanisms in the semiconductor AEC industry, namely: (1) Promote meetings between specialty contractors and designers in early design, before design-build teams commit on design parameters and designers start developing the design based on those parameters. For instance, to develop the early design for a tool hook-up project, specialty contractors, designers, and owner representatives worked together in small groups during two consecutive days. During those days, they jointly agreed on major design decisions and production choices, resulting in significant process improvements during detailed design and construction (Miles 1998). (2) Co-locate people such as engineers and detailers working for design firms on site while construction progresses. Co-locate detailers working for contractors in design offices side-by-side with detailers working for design firms during the design detailing stage. (3) Promote meetings between selected suppliers and specialty contractors. For instance, on a United States hook-up project involving tools manufactured in Japan, the owner arranged for the tool manufacturers and suppliers to meet in Japan and provided language translators to intermediate the meetings.

Regrettably, providing the means for people to meet is insufficient to guarantee effective communication. Communication may fail to occur when people working for specialty contractors are brought to design co-ordination meetings without proper guidance. Given that these meetings are large (they may involve 20 or more people, including designers and owner representatives), it is natural that those who intend to share what they know, may not get a chance to voice their ideas or, for other reasons, opt to remain silent. Our present research therefore focuses on types of knowledge specialty contractors may have. We are not yet looking into the organizational issues related to knowledge transfer.

Alternative means exist, however, for organisations to guarantee that available knowledge is effectively shared. In one project we visited, one owner representative met periodically with specialty-contractor foremen working so as to get their feedback on the design being developed concurrently. With that feedback in hand, the owner representative then went to co-ordination meetings with design leads and brought up the suggestions made by these foremen.

INCENTIVE SYSTEMS

To involve specialty contractors early means to involve people with construction experience, such as labour managers and foremen in the early design effort. Experienced labour managers and foremen are key people on site so they typically are very busy. Although specialty contractors may have the flexibility to pull one or two of their most experienced people from a current job so they can spend a couple of days in early design meetings, they need to be assured that this is worth doing.

Other industries offer examples of incentives put in place to get the right people from suppliers involved in product development (Womack et al. 1990). Similarly, design-build organisations should try to foster long term relationships with specialty contractors, rethink actual contractual practices, and reduce their pools of specialty contractors so that the latter will recognise that their effort in early design is likely to yield business in future. Current practice shows that AEC organisations are moving in this direction. We know of several owners of semiconductor facilities that have reduced their pool of MEP trade contractors to a steady few for each specialty.

LIABILITY

The assignment of professional liability in current practice raises a far from trivial issue. Traditionally, designers have assumed liability for their work. When specialty contractors propose significant changes to an original design, designers have to grant approval. In doing so, they typically add the clause that approval does not make them professionally liable. This clause may not be enforceable in practice. Nevertheless, when specialty contractors participate in early design and contribute their knowledge to design definition, practitioners have to revisit who is to assume what professionally liability. Specialty contractor liability naturally will increase. In the aforementioned example of the plenum body, for instance, the specialty contractor assumed liability for the entire modular design. Recent acquisitions of design firms by specialty contractor firms confirm that specialty contractors are ready to assume more liability. Such acquisitions create engineering capabilities in contractors as well as the professional competence necessary to assume liability for design.

DESIGN ASSIST

Owners, designers, and general contractors may leverage the knowledge of specialty contractors by inviting them to serve in a ‘design-assist’ role. This practice is common abroad (e.g., Hughes et al. 1997) and is becoming more common in the United States. It means that one specialty contractor for each key trade, whom the design-build team perceives to be a highly qualified professional, is invited to participate in early design meetings. This is often done without a contractual commitment that the specialty contractor will be doing the work later. (Alternatively, some contractors are paid to deliver value engineering services but are then excluded from bidding.) The design-build team expects specialty contractors to help in estimating the construction cost, propose alternative design solutions, comment on the constructability of the existing design, etc. To some extent, specialty contractors will convey their knowledge to the design-build team and thereby influence the design so that they are in an advantageous position to later competitively bid, provided they remain interested in the project. Participation in design assist meetings also provides the opportunity to get to know the people they may later have to work with. Based on the perceptions they develop during these meetings, specialty contractors may later adjust their bid, though not necessarily lower it if the insights they gained into the project make it appear less interesting.

In addition, design assist meetings are not necessarily effective in promoting the transfer of knowledge between design-build team players. A design-build manager working for an electrical contractor told us of a design assist meeting to which he carried a one-line diagram representing a design concept his colleagues had specifically developed to the project. During that meeting, he chose to not disclose the drawing because he was not confident enough that the project would be his. It is natural for people participating in such meetings to go by gut-feel reactions and fail to disclose useful information, given that there is no guaranteed reward for cooperation. Design assist meetings are most useful when participants have a clear understanding of what information will benefit the project and them most.

CREATING EXPLICIT KNOWLEDGE IN AEC ORGANISATIONS

This paper has reported on types of knowledge a specialty contractor may contribute to design. It assumes that such knowledge can be made explicit. Not all knowledge is explicit. Tacit knowledge consists of informal technical skills, intuitions, and insights of individual employees, often captured in the term “know-how”. People often cannot easily articulate their tacit knowledge (Nonaka 1991, Bohn 1994). In contrast, explicit knowledge exists in some kind of support medium (e.g., written down in a procedures manual or charted in a process diagram) that makes it more independent from individuals. It is easier to share and communicate than tacit knowledge is, but tacit knowledge can be shared by means of socialisation and interaction among individuals. By sharing tacit knowledge, individuals may be able to articulate and then convert it into explicit knowledge. In turn, once new explicit knowledge is shared among individuals, it helps to extend each individual’s tacit knowledge base into new knowledge, in what Nonaka (1991) defined as the “spiral of knowledge”.

In the AEC industry, people who work for specialty contractors and design organisations have too few opportunities to interact with each other. The lack of interaction explains why potential contributions of specialty contractor knowledge have not made it into design practice. Interaction is not necessarily favoured from a contractual standpoint. One particular example is that specialty contractors may notice errors and omissions in design documents before they bid work, but nevertheless opt to not inform the designer and bid according to the original documents. Bidding according to the solution they presume will get built, may put them at a disadvantage against competitors. It may also take time to get the problem reported, recognised, and then corrected, when time is of the essence during bid preparation and owners and designers may not have the resources to evaluate design alternatives. Moreover, change-order work tends to be renumerative. A specialty contractor reported, for instance, that he had noticed some valves were missing but he let the error go unreported until he was awarded the project. These valves were needed to block equipment in the system from getting filled with the fluid used in the depassivation of the piping before start-up. The problem was corrected during construction, but because communication between the two parties did not exist explicitly, it was not guaranteed that the designers who missed the valves were informed thereof so they would be able to avoid the mistake on subsequent projects.

A second example of how lack of interaction slows down the process of building explicit knowledge relates to “fitting bound problems.” Fitting bound problems arise when there is insufficient height to install a certain number of fittings needed on a pipe so it changes direction as needed. Fitting bound problems are an intrinsic subject in the education of pipefitters. In subfabs, valves left on laterals and mains to later hook up to process tools above in the cleanroom should be left at 45 degrees instead of horizontally. If they are designed horizontally, most certainly an additional fitting will be needed to turn the direction of the pipe and chances increase that installers will later run into fitting bound problems. At present, designers think of this 45 degree design as common knowledge, but because this knowledge remains mostly informal, it is not certain that everyone knows. Those who do may have learned it the hard way, by repeatedly specifying designs that are difficult to build.

A third example illustrates how the lack of interaction between specialty contractors and designers may delay the resolution of problems. In one project, two cable trays are designed one on top of the other, and at their end, the two merge into one. Installation of the cable trays has started. The contractor is aware that code officials may not approve the transition as designed because it will probably lead to a density of cables that exceeds regulations. The problem is apparently well known at this point among individuals involved in the project, but because individuals think that problem resolution will be time consuming and they lack time to develop an alternative, they postpone its resolution.

AEC organisations should make an effort to create explicit knowledge that results from individuals' interaction. It will help guarantee that novices or people not directly involved in a process will be able to more quickly learn what they need to know, and when people leave, not all their knowledge will be lost. In contrast, other organisations preserve the tacit knowledge of its individuals by formalising it into design rules (e.g., expert systems) and creating opportunities for colleagues to share their knowledge. They also provide strong incentives for experienced people to stay with their organisation. Nonaka and Ray (1993) report cases of Japanese organisations that promote socialisation: they make designers follow the execution of their own designs through manufacturing so they get exposed to other people's perspectives that they would otherwise not be aware of. Similarly, Iansiti (1995) reports on efforts made by organisations in the computer industry for retaining, leveraging, and sharing the knowledge of experienced employees across the organisation.

CONCLUSIONS

Current practice reveals that AEC organisations have only a few mechanisms in place to leverage the knowledge of specialty contractors in design, yet research shows that specialty contractor knowledge is available and valuable. Specialty contractor knowledge may significantly improve the effectiveness of the design and building processes and the quality of AEC products. Management in owner and design-build organisations must gain awareness of the opportunities currently being lost and rethink some of their practices. United States industry data shows that specialty contractors are getting more involved in projects earlier, which signals that awareness is increasing regarding the value of their potential contributions. A challenge for AEC organisations is to implement systematic methods to elicit and disseminate new, explicit knowledge. These methods must be augmented with incentives for individuals to share what they know within the organisation they work for, and with individuals working for alliance organisations.

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