DESIGN PAPER SESSION

Assembling Architecture

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Many of the things that architects have come to consider normal in construction are a response to its disordered character: trades are staged to allow architects and contractors to determine who caused what damage, and the tolerances that are a normal part of design are a direct result of the imprecision of on-site construction. For some, this character creates opportunities; the lack of closely defined processes allows gaps where changes and adjustments can occur, albeit at some cost.

Today, however, there is a growing interest in the industry towards developing approaches to construction that allow for greater efficiency and predictability, better use of a shrinking workforce, and shorter construction cycles. There is increasing reliance on assembling fabricated components as an alternative to conventional on-site construction practices, both one-off "bespoke" components and materials manufactured in large batches.

A limited number of elite architects often draw on off-site fabrication to achieve demanding standards regarding precision and quality. They work with a sophisticated supply network to achieve their aims, and comb the world for the most advanced production houses, for example, German structural paper tubes for tiny projects in New York.

In Asia and Europe, rapidly developing economies have meant significant shifts in living standards. New manufacturing systems allowed the industry to keep up with higher standards, in spite of diminishing working classes which offer up fewer skilled laborers to produce buildings and construction materials. The construction industry abroad has had to rethink its processes, relying in many cases on technology transfer from the manufacturing industry. In some parts of the world computer numerically controlled (CNC) equipment and manufactured customization have far more relevance to architects than any of us might have predicted only ten years ago. A familiarity with off-site production is now a necessity, not a luxury.

It is not my claim that off-site fabrication in architecture is new; the points in history when it was most relevant in the past mirror circumstances found today. The Crystal Palace of 1851 by Joseph Paxton is often cited as one of the earliest prefabricated buildings. Typically, its production reflected the technological advances and demands of an expanding economy in nineteenth century England. At the same time that the Crystal Palace was built, kit-built houses were also common for the same reasons. By looking at periods when off-site fabrication has peaked, it is possible to argue that several criteria are common to these times: heavy, urgent demand (national disasters, times of war production), declines in traditional labor skills (often the result of emerging industries that compete for labor) and related increased labor costs, and the introduction of new production technologies. In much of the developed world, changes in labor conditions and production technologies currently hold true. It may be that the current political situation will also create urgent demand for structures in refugee areas, areas associated with military encampments and war production, and perhaps even the suburbs, as a response to fears about terrorism in cities.

Previous cycles of reliance on off-site fabrication have also left architects with certain expectations and fears regarding manufacturing's relation to architecture. During World War II, the need to build whole cities to support production required rapidly responsive building production systems, but construction quality was often sacrificed – sometimes even to appease local interests concerned about long-term impact of these new worker groups.

Because of the growing importance of off-site fabrication, I have tried to outline strategies for successful links to the fabrication community. I begin by taking a closer look at the potential reasons for use of off-site fabrication in architecture today, I discuss how to identify potentially supportive fabricators, and I then focus on how new production technologies, especially those related to computers (CNC equipment, digital communication, etc.), may or may not promote the increased exploitation of off-site fabrication by the profession.

THE BENEFITS OF OFF-SITE FABRICATION

Among the commonly cited benefits of off-site fabrication, reliance on collaborations with fabricators assures building components of greater precision, greater predictability, and better value, and, when these components are being produced in overlapping cycles, their use and assembly can lead to shorter construction periods. By building in a controlled environment away from the construction site, it is also possible to create ergonomically better and safer working conditions, and sustain less ecological damage on site.

These may all sound laudable. However, each of these attributes reflects a sliding scale of opportunities, rather than clear benefits. The economic efficiencies of fabrication can lead to larger, cheap buildings as easily as they allow for higher quality to be achieved at low cost, and predictability in a sophisticated high tech building has a very different character than when it characterizes hundreds or even thousands of houses in a single area. The precision of off-site fabrication is sometimes blamed for a cold architectural character, and just as the Industrial Revolution also spawned the Arts and Crafts movement, there are architects today who feel that the demand for imprecise materials like rammed earth and straw bales is a reaction to the presence of larger manufactured components in contemporary architecture. Shorter construction periods may allow towns to sprout up without the time for supporting infrastructure and community to grow, or for professionals to think and respond to local opportunities and problems. And even the use of a controlled environment for fabrication, while it assures workers steady employment, greater safety, and ergonomically-tuned workplaces, also allows management to establish Taylorist practices that reduce the need for skill and keep laborers' wages as low as those of fast food workers. This reliance on minimal skills leaves laborers with little room for advancement or intellectual challenge. Finally, the ability to avoid damaging ecologically fragile sites with construction also tempts local planning authorities and clients to build in areas they otherwise might not, and perhaps should not.

In fact, one of the few virtues of fabrication that it seems all can agree on is the fact that by concentrating construction practices in one place, fabricators can reduce waste and enhance recycling practices. In addition, in supportive environments, there is some opportunity to use off-site fabrication to pre-assess or pre-test those components which are particularly important to a construction.

Clearly, fabrication is not a cure-all alternative to on-site construction practices. And while greater reliance on manufactured production has created a bland, monotonous landscape, such problems are also not the universal result of relying on fabrication. The range of potential impacts simply serves as a reminder that architects must successfully consider how to effectively engage with off-site fabrication in order to achieve the best results.

A CHALLENGE TO THE PROFESSION

As a profession, we lack a structure for determining the reasons for deciding where and when off-site fabrication is appropriate, and an understanding of the range of choices and responsibilities that are inherent in choosing to rely on fabricators. There is little literature available on the subject, and the range of interactions with fabricators at first seems too broad to suggest obvious lessons. Furthermore, too often architects have found their initial efforts to work with off-site fabrication inefficient and frustrating, because effectively utilizing the fabrication process requires rethinking the earliest stages of the design process.

It is my contention that the nature of the interactions architects have with off-site fabricators has very little to do with the output — that is, with whether one hopes to use wood, concrete, steel, or glass — and much more to do with the processes of production, and how to effectively engage them.

Off-site fabrication ranges in production size from a single component to batches of hundreds or thousands. One of my assumptions is that most architects who read this article are interested in understanding how fabrication systems can be engaged for the production of customized and small batches of components. This is based on two assumptions. First, the point where individual architects have the greatest potential impact on production is not in large batch production, but in smaller batches. Secondly, while access to some level of standardized production is already the norm, the few architects who are engaged in production systems influencing large batches are supported in conferences associated with production (AIA, ULI, etc.) while ACSA serves a population with more hands-on and singular goals.

This is not to say, however, that I feel the differences between the two communities I have identified are ones I celebrate. Buildings that rely on off-site fabrication are only as good as the demands placed on them. In that regard, by ignoring the opportunities of off-site fabrication at all scales, academics and studio architects assure that our work is increasingly irrelevant to much of the construction industry, and that the architects who have chosen to work with large batches have proportionately greater impact upon the fabrication community.

CHARACTERISTICS OF PRODUCTIVE ARCHITECT-FABRICATOR INTERACTIONS

[Subhead 1.] Finding Fabricators

Most fabrication houses will have an economically acceptable production range based on number of units in a batch, from highly standardized pieces in large batches to highly customized single unit production. Fabricators will have a sense of the number of units it is necessary to produce to achieve a profit; this expectation is based on the cost of equipment and the relative costs of various labor inputs, and the price the market is expected to pay. Generally speaking, fabricators will assume that fewer units in a batch will lead to higher costs per unit, because each component requires some attention to set-up. If the customization costs can be covered by a higher price tolerable to the market or set-up costs are low, then the fabricator will support smaller batch size.

Fabricators that have a substantial portion of their work dedicated to high-return small batch and customized production are also more willing to take on challenging or unusual work. These firms have staff and systems in place to support small batches, and the names of supportive producers (such as Permasteelisa) will turn up repeatedly in association with well-funded work by leading architects. The costs of pre-production services are passed on to clients. However, these more generous budgets are not often enjoyed by emerging architects. Fine-tuning and design support are also common when working with a small, craft-oriented fabrication shop, and while here again, craft is often achieved at a higher price, clients may be more flexible about the incorporation of handicraft than industrial fabrication.

On this basis, the profession has developed the expectation that design support exists generally in small fabrication houses. However, a visit to any good-size structural steel or curtain-wall fabricator will quickly prove this assumption fallacious. It is not the size of the contract that is important, but rather the size of the work relative to the size of the plant. A project that represents a significant volume of the plant's work at a given moment will naturally receive greater support and attention, whether a single door produced by a small shop, or a large, complex structure produced in a larger one. Nonetheless, for the novice first pursuing collaboration with fabricators, the small project carries less risk and may be an appropriate point of entree in collaboration.

An additional concern is the relationship of a project requiring attention to other work in a plant. Where there is a constant, reliable demand for large numbers of some unit, there is less incentive to serve the one-off customized side of the production stream. In my experience, most fabricators have at least some proportion of their work that can be measured in the hundreds or even thousands of units annually. The higher this unit number and the greater the proportion of output this represents, the less likely the fabricator is to engage in customization. Here, digital technologies have exacerbated the problem, in that a relatively small but constant demand for a material can be filled irregularly and with little retooling or additional up-front costs, biasing fabricators to routine production.

Locations with a range of fabrication shops, from large to small, seem to offer the greatest opportunities for designers to learn how to work with fabricators. Not every fabricator is interested in taking on small batch and customized work. Some will be disinclined regardless of profits, simply out of a lack of interest or a low tolerance for the ambiguities found in the initial stages of any collaboration. Architects have a better chance of finding willing support from collaborative fabricators in a dense urban area.

Architectural/design offices may also have a problem working closely with collaborating fabricators that are distant, because of the greater cost of finding the appropriate fabricator and the costs of initiating two-way communication. For this reason, success is more likely when working with fabricators in the office's region (where access to information may also be greater) or, if the office makes it a point to travel to sites with some regularity, possibly in the area of the site. Where neither of these conditions is true, the firm must pass the higher costs of communication on to clients. These are ways that architects located in communities with rich fabrication support are advantaged over those in less populated areas (or areas where tourism or services rather than manufacturing and fabrication dominate the local economy). Clearly, information technologies can help overcome the costs of finding and working with appropriate fabrication plants, but to date this remains surprisingly difficult; an internet search using a term like "custom stair" will readily make this apparent. The potential for such information to be accessible is much higher than the reality, and word-of-mouth has still been the most effective way to make contact with appropriate fabricators.

Finally, there may be some opportunity to get support from a desperate fabricator, although quite often the business problems that led to the fabricator being desperate in the first place intrude into the new work. I am aware, for example, that Bay area experiments with prefabricated fast food outlets probably failed in part because the fabricator was unable to produce durable, long-lasting finishes and the buildings have not stood the test of time.

[Subhead 2.] Production Range And Cost/Profit Centers

Expectations for CNC and CAD-CAM equipment suggest that new controls technology can reduce tooling costs. However, costs remain. A high cost differential between up-front labor inputs (whether digitization of information or old-fashioned equipment set-up) and the standard labor costs on the shop floor generally cause the fabricator to be reluctant to support customization's greater up-front service requirements. As one example, in a large-batch-oriented fabrication shop such as a panelizer (producing stud walls in a factory), the most expensive work is related to laying out individual walls and digitizing this information, work done by the company's more skilled, more highly paid employees, whose salaries are three- or even four-times the hourly pay for those on the floor. The fabricator will want to capture these costs by spreading them across as many similar units as possible, and will have a bottom threshold of units that is considered profitable – in the case of one panelizer I deal with, five houses. (In a shop requiring greater craft, such as one with brake presses and benders, the differential between the cost of white-collar and shop labor may not be significantly different, but there would still be a desire to spread the set-up costs across a number of units.)

I should note that information technologies do have the potential to overcome this problem. Today, most panelizers use software developed in-house (what one of my students called "roll-your-own" softwares) to generate the Mylar tapes or graphical projections used to direct low-cost, shop-floor laborers. If the industry – or the design professions — were to find reliable software that a majority of producers chose to use, then there would potentially be an incentive for at least some architects to share in digital production. Since this kind of work would not require significantly different skills from other architectural production, there would be less incentive to squeeze it out of the system, potentially making customization more practical in such industries. A second way that such engagement could occur is if translation softwares become acceptable. Many already exist, but the fabricators are reluctant to use them because they do not offer sufficient checks on the accuracy of inputs, and architects (they claim) show a sloppy disregard for the importance of numbers adding up and geometries meeting.

In these areas, I see new technologies working at cross purposes. While the set-up for new equipment requires white-collar technical workers for input, CNC and CAD-CAM equipment has reduced the cost of tooling and old-fashioned craft on the floor. Furthermore, higher equipment costs for sophisticated machinery may create an incentive for the fabricator to keep the equipment in use. With new types of equipment, the initial costs of using them may even be artificially kept low, in order to expand awareness of potential capacity in the design community; I would argue this has been the case with water jets and laser cutting equipment, where the differences in labor and set-up costs between conventional cutting and these technologies was passed on by the fabricators in order to expand the market.

A third area that is important to consider when looking for customization opportunities in a fabrication shop is the presence of other down-stream profit centers in a plant. These may be used to balance low-profit and high-profit production. As one example, framing panelizers exploit the decline in carpentry skills found on site. Most supply trusses (which supplant rafters, with their more complex geometry) – indeed, these may be the first reason contractors turn to panelizers – and many also supply customized materials such as ornamental rafter tails, gable vents, shutters or even stairs. The panelizer is likely to have some areas of greater customization which may not be at first apparent to the design professional.

As an aside that shows how difficult these synergies are to assess, by contrast, one of the curtain-wall fabricators I know well also sells interior doors from the same shop. The initial point of interaction (in this case offering unitized curtain walls in stone, metals, GFRC, etc.) is clearly the one that offers greater customization and the latter work is highly standardized. The fabricator saw an opportunity for greater profit in the doors, because the company would be involved in the project at an early stage and could capture this work. My point is that not all packaged strategies have equal value to the design team.

[[Subhead 3.] One-way Vs. Two-way Forms Of Communication.

The nature of communication between the architect and the fabricator, and the media used to communicate, is by far the most significant aspect of the collaboration. In North America, it may also be the most difficult challenge to the architect, since tradition has been biased towards a one-way communication system of drawings, shop drawings and mark-ups, with no opportunity to explore or discuss alternatives. Contractors today have a tendency to want to maintain the status quo, but even in nations where one-way communication is less conventional, contractors like the control such a system offers. The contractor can act as a filter, biasing information between the architect and fabricator towards those values the contractor holds dear.

One-way communication approaches reinforce antagonistic relationships in the profession. In a one-way system, incompatible knowledge sets and values will lead each party to consider the other potentially foolish. In two-way systems, the fabricator and architect educate each other in a way that can render them more effective across disciplinary boundaries.

Where conventional design-bid-build arrangements are based on a primarily one-way approach to communication, the design must be finalized before bids are collected, and shop drawings are used to maintain the quality of the original design, not as iterative tools in design development. Ideally, the design is communicated in a way that assures quality without being specific to production systems or a limited set of suppliers. Architects may well customize components under this arrangement, but the nature of communication makes changes during the construction phase, even those intended to capture opportunities presented by the specific capacity of selected fabricators, potentially costly. Lead-time is also longer than in collaborative systems, and the architects' choices, which are based on incomplete knowledge, may be overly conservative.

By contrast, two-way systems of communication must happen early in the design phase, in order to capture the specific opportunities and knowledge offered by a fabricator. Where an architect is uncertain how to achieve an effect, or needs test pieces done in order to develop a design, two-way communication becomes necessary. It is important to reiterate that collaboration at this point in the design and construction sequence is contrary to conventional bid procedures because fabricators will not have an economic reason for offering a high degree of specific support where there is no assurance of a contract. However, the shorter lead time that results from such collaborations can offer some off-setting savings and some economists feel that consultation with the fabricator can lead to more efficient production practices, offering potential cost savings. If the fabricator also recognizes the architect's interest as having the potential to lead to on-going work, these savings may be shared across the design team.

New technologies have a significant impact in this area. Most fabricators I speak with no longer feel it necessary to have frequent face-to-face conversations; an initial meeting and a visit to the shop floor (or even constructed buildings which reflect the value systems of one of another of the collaborating groups) can be followed by regular contact through e-mail (using graphical attachments) and the occasional telephone call. This reduces the time necessary for the most costly area of architect interaction, which in turn makes the fabricator less reluctant to offer such support (a point I will return to below). Architects, however, can make the process more cumbersome if they are not quick about responding to such communications.

Related to this point, two-way communication can be further enhanced by return business, allowing the architect and fabricator to develop a deeper understanding of each other's interests, goals, and values. In on-going relationships, when one or the other member of the team develops new insights that have value for the other, they will make a point of retaining this information for future interactions, enhancing the productivity of the relationship. I do not see any direct way that on-going relationships are enhanced by new communications technologies (expect perhaps in the ease at which many offices can now create and send sophisticated electronic newsletters), but as the costs of transportation and remote supervision drop, the fabricator may be drawn into a greater number of projects designed by a single architect.

CONCLUSION

The potential for off-site fabrication, especially in the area of customization, to be enhanced with new technologies (especially, in my mind, new communications technologies, rather than new machinery controls) exists, but is offset where there are significant cost differentials between labor on the floor and up-front labor costs. This is clearly an area architects, by improving access to and participating in digital production, have the potential to make a difference. However, the presence of in-house softwares presents a formidable barrier to success. Additionally, architects in North America have been moving in the opposite direction, towards less technical knowledge, as a way to protect their firms from liability costs. Fabricators, responding to similar concerns, may also be unwilling to engage in two-way collaborations that increase their exposure. In the end, much depends on whether other factors, such as urgent demand, will press the issue.

SOURCES

Much of this paper is based on first-hand observation of fabrication communities and discussions with my students on off-site fabrication during the Fall terms of 2000 and 2001. I am particularly indebted to Cynthia T Y Tsao, Z Smith, Erin Moore, Chesney Floyd, Jody Estes and Brian Padgett for their input.

The following texts are recommended for further discussion on off-site fabrication:

Gibb, Alistair G.F, *Off-site Fabrication.* New York: Wiley, 1999.

Buntrock, Dana. *Japanese Architecture as a Collaborative Process: Opportunities in a Flexible Construction Culture.* London: E&FN Spon, 2001.