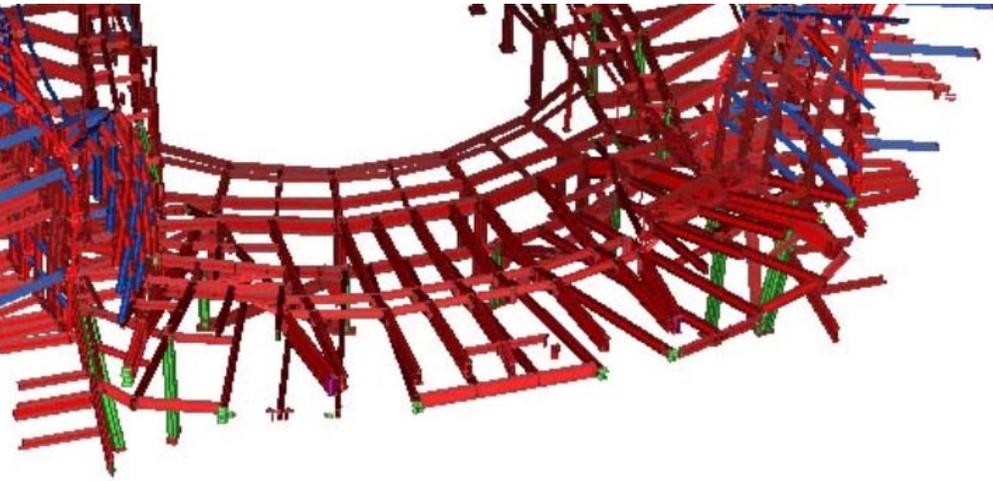# New Methods of Architecture and Building

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### Abstract

Three conditions exist that are likely to lead to significant restructuring of the construction industry. These are (1): the recognition that traditional contracting practices are inefficient and costly to the client, (2) the growing availability of information-rich 3D parametric modeling, and (3) the strong interest in integrating the issues of design and fabrication. Some aspects of these conditions are examined using two examples: parametric design and integration in steel structural design, and in fabrication-level modeling of precast concrete. The implications of these changes are explored.

### Introduction

The history of architectural design is largely based on tacit, craft knowledge. All members of construction have worked within the framework of the construction industry and its practices, with regard to how to frame a wall or roof, how to prepare a foundation, or to install electrical systems. Construction has been a craft, widely understood by those within it (Davis, 2000). The architect was a mem-

ber of the craft and worked within it. When I studied Architecture at Berkeley, one of my professors was Leo Bernardi, of Wurster, Bernardi and Emmons. He was a young draftsman for the San Francisco City Hall, constructed in 1915, and beautifully photographed in the James Bond film *A View to a Kill*. He brought in the construction drawings for the project, consisting of eight sheets (sized 36" x 48"). These few drawings were sufficient because of the shared understanding of the methods of construction and use of materials. The contractors knew how to build; the architect's design guided them in what to build.

Over the intervening 90 years, the practices of building have evolved greatly. The easy, close-working relationship between designers and builders has been largely disappeared. The easy mapping between an architect's intent and its realization by a builder cannot be assumed. The evolution to more complex construction methods and building systems, more complex programs (for example for airports, and hospitals) have made earlier tacit knowledge inadequate without far more explicit definition. Within buildings, there is also more complexity within the relevant building systems: for lighting, air handling, energy management, fire and safety systems, energy communication systems, materials handling, power management, garbage and trash management, and building maintenance, among many (Rush, 1980). Today, there are far fewer building craftsmen; the role of unions has disappeared in most areas of the country; the training of construction crews is limited. Modern contracts and the delimited roles of each party have led to strong adversarial relationships and resulting liability claims (Sweet, 1993).

New roles have arisen in the construction industry to address these kinds of complexity. Construction manages and client representatives have intervened between architect, client and contractor, to address costs and completion time oversight. Building commissioning has emerged to address the operationality of the complex systems that are embedded in buildings. The architect's role has been chopped into and reduced, his or her roles further delimited.

In contrast, we can recall and revere the stories of Antonio Gaudi, building his highly evocative Barcelona buildings, using gravity methods for structural analysis and setting up a model shop on his construction site as an example of a relationship where the architect was the central role in building, being the master of building activities.

### The Opportunity
Today, three related issues in architecture and construction have converged to provide a unique opportunity for reconfiguring the roles in which architects, and to a significant degree contractors and other building professionals, are enmeshed.

It is widely recognized that the current methods of contracting, usually referred to as *design-bid-build* are inefficient in both time to completion and building costs, promotes litigation, and restricts innovation. Alternative methods, including construction management and design-build are being explored, with others (Quatman and DharRandy, 2003). The implication is that the traditional organizational frameworks in which architects have practiced are undergoing change. An important aspect of any such change will be to integrate the design work more integrally with the other parts of the building procurement process.

Another change is that the long awaited move to production-oriented 3D modeling, based on rich object models and parametric design, is finally moving to realization. These capabilities will finally allow the demise of architectural drawings as a contract of record for a building project, and replace it with a highly annotated 3D model. The new software systems capable of generating such building models have received the new name of building information modeling (or BIM) to signify the transformational nature of this step within the overall construction industry (Eastman, Sacks and Lee, 2004)

Building information modeling, as we all know, has the potential of constructing the building inside the computer virtually, before it is built on site. It brings together the issues of design, fabrication and erection,

allowing the design team the ability to better address issues of fabrication and erection that have not been practical up to now. If we take the title of this conference literally, fabrication is only part of that process facilitated by BIM. Other aspects include procurement, behavioral assessment, erection, operations, and others.

The third change, and the focus of this conference, is the re-invigorated exploration of new fabrication processes used in construction. The new methods of fabrication are motivated by the desire to support the construction of new building forms. Because the forms are unrealizable within the framework of traditional construction methods, additional work by the designer is required to detail how the structure is to be constructed, including the fabrication of parts, their grouping into assemblies, and their erection on site. This change requires the architect to more fully detail the parts, or to collaborate with the fabricator to make sure the design intent is realizable and effective.

These three events, one organizational and business related, the other two technology driven, provide the opportunity for the architectural field to recapture a more central role in construction. In the successful projects described at this conference, the architects and contractors are working together, sharing end result, methods and procedures very different from the case of the San Francisco City Hall, where the construction practices were already shared and the architects role on the construction side was minimal, providing only the what and not the how. We have the opportunity to take the lead in construction technology and to again provide the integrative and overall vision that is required of outstanding architecture.

### Building Design for Manufacturing

If architects are to take more control of the building process, we need to better understand what is needed to put buildings together. That is the theme of this conference. Fortunately, in parallel with the development of new BIM tools for architects, BIM technology is also being developed for major building systems. These software tools encode much of the expertise of specific fabrication areas, and make accessible far improved communication and coordination with fabricators. They can be used in schematic design phases to assess costs and construction times, before major

design commitments are made. These tools support a designer's need to integrate fabrication issues into their designs, to show that they are easily buildable.

Architects in school typically learn only a little about the whole practice of construction, and only partially about how buildings are produced. It was a shock for me the first time I reviewed a set of contractor-produced coordination drawings, and the shop drawings of the steel fabricator or curtainwall fabricator. These drawings were greater in number than the architect's contract set. The re-design and fabrication of these systems require much additional information that is not typically part of the design information. I turn to two industry segments with which I work, the steel fabricators and precast concrete producers.

### 1. Steel Fabrication

In North American practice, steel design is only taken to the member sizing level through contract drawings. Structural engineers define the moment releases and boundary condition behaviors of connections but do not design them, nor typically address the effects of notches, cutouts and other details that show up in making everything fit together. Shop fabricators typically detail these issues and design the connections. They also determine what pieces are assembled in the shop, and what are the units of erection. All of these have important effects on some designs, and in their cost and time to build.

Over the last eight years, steel fabricators have moved from using AutoCAD and Microstation to using 3D fabrication applications by Tekla, Design Data and AceCAD, companies not very familiar to the architectural community. Today, about fifty percent of the steel fabrication shops are 3D-based, using one of the three packages. They use the 3D models to produce the bills of material for costing, the cutting and drilling lists for computer-numerical-control (CNC) and piece and assembly drawings for fabrication.

The steel applications have varying degrees of design automation. A big productivity enhancement is automatic connection detailing, allowing a user to set up a set of design rules that can go through each connection and automatically trim connection members as needed, select the type of connection, based on

structural loads and geometry, and apply all the clips and plates, bolts and welds needed to produce that connection on each of the pieces joined. This automation can run through a large structure in a short time (minutes) whereas a person would take weeks. Also, some of these packages automatically update the connection if any of its inputs change, such as member size, angles, loads etc.   External systems can be placed, with automatic cutout spacing for them. These too can be automatically updated, making sure that any revision will not forget them. The steel detailing software allows the production of much more accurate information, guaranteeing that all connections are consistent regarding all the pieces they bring together; they guarantee no spatial conflicts (within the modeled entities, and provide full production information for all shop processes. They provide this information is shorter time than drawings, significantly improving steel fabrication throughput.

Today, all the steel industry 3D models are built from scratch, based on digital 2D drawings. They can gain significant production efficiencies and quality control improvements using 3D modeling.

The workflow for structural steel alone is complex. While much of this information flow takes place within the fabrication company, there are also important links to material suppliers, structural engineers, architects and contractors. These flows vary somewhat from project-to-project, and whether it is design-build or design-bid-build, for example. The American Institute of Steel Construction (AISC) in 2000 adopted a special purpose building product model called CIMsteel version 2 (CIS/2) to support the automation and integration of these workflows through an exchange data model. GA Tech is the technical advisor to the AISC in the deployment of CIS/2. Currently twelve steel applications have validated interfaces with CIS/2 and more application interfaces are in development (GATech CIS/2, n.d.). CIS/2 has been used on a variety of projects and is part of the workflows in many fabrication shops in the US and Canada as a file exchange format. Work is underway to offer product model database repositories for CIS/2 (Eastman, et al, 2004).
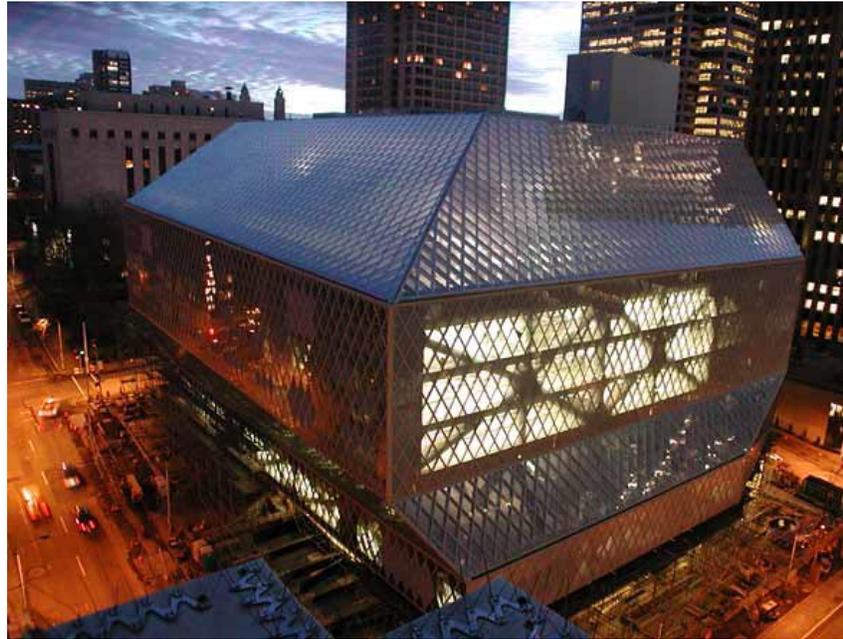


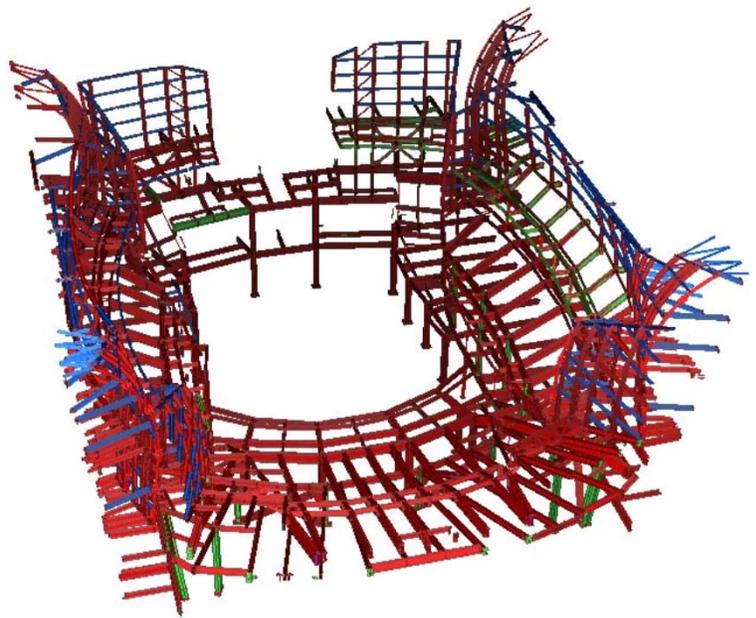*Figure 1. Koolhaas' Seattle Central Library shows off its steel framing.*



*Figure 2. The steel framing for the Disney Concert Hall, developed on Tekla Xsteel.*

CIS/2 is the most advanced example today in the construction industry of a set of 3D model applications integrated for seamless use by a product model. The 3D applications are widely deployed, here and around the world, and CIS/2 is in production use here, in the UK, and soon we hope throughout Europe.

At the first stage of implementation, CIS/2 offers faster and robust translation between applications, often invisible to the user. But secondly, it offers the ability to support new workflows. It has been frequently used in design-build projects, allowing early identification and procurement of long lead-time items, to speed and reduce review processes, and to facilitate concurrent design, scheduling and procurement efforts [ref].

One important point of how the steel fabricators moved to 3D and software integration is that they had clear financial benefits for doing so – they could work faster and reduce errors. They could sell more steel. Thus there was a business model. Another point is that these applications can embed a large amount of design knowledge. They can detail the design according to design rules, in a production form somewhat reminiscent of shape grammars, as developed by George Stiny (1980) and applied by Seebohm and Wallace (1998), among others, to building detailing. They make apparent the communication needs of steel fabricators, and facilitate their earlier involvement in projects.

### 2. Precast Concrete Design

Another case where BIM is being developed at the fabrication level is in cast-in-place and precast concrete. Precast concrete is a construction material with growing applications, both for building parts, such as facade panels, structural systems and stadium seating, but also for whole buildings, such as offices and parking garages. It offers a wide variety of material finishes and custom shapes. The product is highly engineered. In addition the structural and thermal properties of each panel is defined for each piece. Like other building materials, it must also interact with other systems, such as mechanical, electrical, and other kinds of building systems. In addition to its final structural requirements, it must be designed to deal with loads during transit and erection.

Like the steel fabricators, precast fabricators have been using AutoCad or Microstation for definition of the assembly drawings, then the piece drawings needed to define the shape, for each piece and the various rebars, pre-tensioning cables, plates and any other special hardware required. They rely on both formula-based analysis (because many of their parts do not have moment connections), and also finite element structural models, for large structures.

In general, the precast concrete industry is considered small, about one fourth as large as steel, in terms of revenues. There have not been specialized CAD applications developed for the precast concrete industry, as there has for the steel industry. A number of precast companies have developed 3D model applications in-house, but these always became obsolete and were very incomplete.

Georgia Tech worked with a consortium of initially 23 companies (called the Precast Concrete Software Consortium (PCSC)) to develop a specification for a 3D modeling precast concrete shop model application that all the companies would agree to buy, and put it out to bid for possible software companies to develop. They were asked to submit what they would supply (all or part of the spec), and a business proposal involving possibly up-front support, guaranteed purchases, or whatever incentive they required to develop the product. The specification assumed that the product would be developed on top of a parametric modeling platform, with customized geometry to define any type of precast piece. (See Fig. 3). Automation on top of the geometric and property management scheme could be extended by writing plug-in applications to support further automation, including piece design, including tensioning and reinforcement in response to local codes, mold design, or even whole structure design, for example for parking garages. The consortium received 12 proposals, which were quickly reduced to six (the rejected ones were either too small and risky, or committed to too little of the sec, or similar reason).

After site visits, benchmark tests, interviews with all proposers, the contenders were reduced to four, then two, then a final selection was made that Tekla, a Finnish-based company, would provide both the platform

and the customization of it for precast. They are one of the main developers of steel detailing applications and had strong experience in the AEC industries.

After careful joint development of a detailed specification, incremental release of 2 beta releases, we are two months away from their production release. The product is already being used by the precast companies doing pilot projects, they have been further customizing it with special connections, company-specific pieces, and at least one structural analysis interface has been implemented.

In this case, this package is designed to support the design of almost any architectural facade in precast concrete, as well as structural elements, wall and decking panels. Both the precast consortium and Tekla would like architects to become users of this system, so that architects could generally design with the high level knowledge needed to design in precast.

The Tekla software, even more than the steel software, incorporate expert knowledge about its systems, for example with regard to the camber that a member takes, when it is tensioned, or the amount of warping a double tees or hollowcore can take to ramps or to facilitate roof drainage.

### Some Implications

The two systems reviewed can also be used schematically, as well as for fabrication detailing. Standard steel or precast pieces are used to lay out the general structure or façade, with typical detailing. This can be done quickly, in only a few hours. Bills of material and fabrication schedules can be generated, providing quick feedback on candidate designs, before the design is detailed or even before contracts are set. They facilitate early exploration of procurement, fabrication, shipping and erection issues. But they can only be used this way outside of current standard practices.

Most discussion about parametric modeling and fabrication has focused on its application to structural systems that can support new building forms. Most of this effort is directed to skin and rib structural systems, allowing the skin and structural rib system can be controlled together (Kieran and Timberlake, 2003). However, there are many others, which may also become
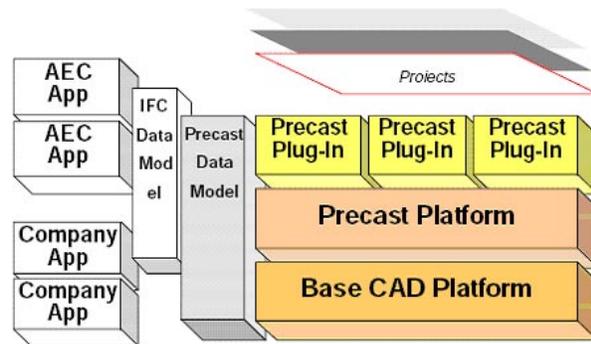


Figure 3: The system architecture of the Precast Concrete Software Consortium specification



Figure 4: Some complex forms and detailing with precast concrete
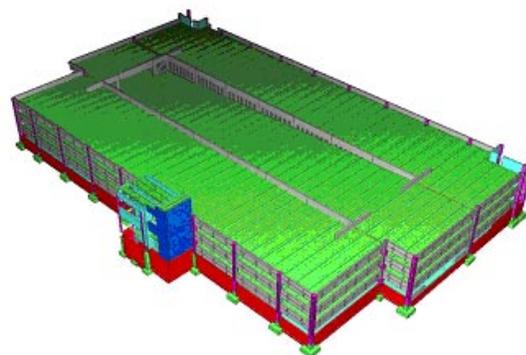


Figure 5: A pilot project structure defined by Strescon, a Canadian member of the PCSC, and the typical detailing inside each of the pieces

mainstream. These includes spaceframe grids, such as those being developed by Foster in the British Museum, or Gehry's Museum of Tolerance in Israel (Glymph et al, 2004). They may include rigid shells with integral structure, like the failed forms at de Gaulle, or the roof structure of the Dulles and TWA airports. Both of the systems reviewed here, for steel and precast concrete, are frame systems, with the precast also offering decking, wall and other elements. Both are well-developed systems, with quality control and standards for tolerances. A body of good practice has been developed for them. If a market of any size develops for any of the newer skin and rib or shell systems, we will begin to see design packages developed to support both their design and fabrication also. That is, the new parametric modeling systems support the embedding of design rules and thus technical knowledge, facilitating the use of that particular system of construction. We will see the development of many further detailing systems for buildings, not only for construction systems, but also for particular types of space and building types.

While the steel and precast and other fabricators have an incentive to move to 3D, what is the financial incentive for architects? Technically they are paid for the service of designing and recoding on paper their designs, so downstream the design can be built. The fees are typically set as a percentage of the construction cost. They are not paid more in current AIA contracts, if they provide fabrication information. Liability insurance does not cover errors that might be produced in any provided fabrication information. Construction time is not a performance variable in current standard contracts. There are no economic incentives for architects to move to 3D, if their role is to provide drawings. New business structures are thus desperately needed to allow architects to take advantage of the opportunities of the modern age.

We are at the time in history to make adjustments to how architects practice. The role of architecture in the next ten years can expand, or shrink further. The tools are available that can allow architects to know what they can build in steel of precast, and provide that kind of close coordination that benefits clients and society.

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