DEVELOPMENT AND IMPLEMENTATION OF ADVANCED IT IN THE NORTH AMERICAN PRECAST CONCRETE INDUSTRY

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SUMMARY: *We report on a large-scale effort to integrate advanced design and engineering information technologies (IT) in the North American precast/prestressed concrete industry. The effort has been undertaken by a consortium of precast producer companies formed specifically for the task. The effort involved significant process modeling work, using a unique method and set of tools. It led to the development of a specification for an advanced precast concrete design and engineering parametric application platform, which is currently being implemented by a major building modeling software company. The problems and lessons learned are reported. The project reported is on-going. With the first phase now well established and underway, the groundwork for the second phase – development of a Precast Building Product Data Model – will soon begin.*

KEYWORDS: *parametric modeling, precast concrete, information technology, design system, engineering system, product model*

1. INTRODUCTION

The North American precast concrete industry has only a small share of the building construction market. This is in contrast to much larger market percentages held by European and Scandinavian precast industries. At the same time, the structural steel industry, a competitor, is visibly undertaking new advanced IT initiatives that allow them to reduce fabrication costs and time to completion. In response, a small number of precast industry leaders held informal meetings during 2000 to explore what kind of initiatives their industry might undertake. They invited representatives from universities, software companies, European initiatives, and the International Alliance for Interoperability (IAI), to meetings to explore what could be done in the area of IT in the precast industry. These meetings explored alternative developments, such as an industry data model, automated design software and enterprise resource planning packages, among others. In September, 2000, a group of five industry leaders selected Georgia Tech representatives to develop a "white paper" for the industry, laying out its challenges and a plan for future initiatives (Eastman and Augenbroe, 2000). In January 2001, the white paper was submitted and then presented to an open meeting of industry executives called for this purpose. After review, these leaders endorsed the five-year plan and engaged GA Tech to help them implement it.

This paper first reviews the context of precast concrete in the North American construction industry. It then reviews the five-year plan developed by Georgia Tech, its logic and its partial implementation, up to this point in time. The paper reports on the procedures developed for carrying out the initiatives and identifies some of the challenges and issues to be addressed in such an industry-led initiative. It then reviews lessons learned by the research team with regard to what was required for the process to be successful. In several respects, the North American precast concrete industry can be viewed as an example of the transitions likely to take place in other segments of the North America construction industry.

1.1 North American precast/prestressed concrete construction1 industry

Precast concrete is recognized worldwide as offering significant potential advantages as a construction method. In exchange for offsite fabrication and significant capital investment, it provides building components with high levels of design flexibility, significantly improved quality control over on-site construction, fast erection, and reduced costs. Precast concrete is a significant contributor in many building types, including commercial, institutional and parking garages. It was first introduced into North America in the 1920s, but became more widespread during the 1950's, with increased use of prestressing (PCI, 1999). Nevertheless, the precast concrete industry's share of the construction market in general, and reinforced concrete in particular, is small in comparison with other industrialized regions (Sacks et al., 2003). Table 1 shows the US market share of the industry for various building types (PCI, 2001). The total is 1.2%. The largest single market is that for parking deck structures, with $1,010M, representing 12.9% of the market. In contrast, in Finland, for example, 25% of all structural slabs and 11% of all building facades are precast (FCIA, 2000, RTT, 2001).

Table 1. Precast Market Share in the USA, Year 2000 (PCI, 2001).

Building Type	Precast Concrete ($m)	Total US Construction ($m)	Precast Market Share
Public and Commercial Buildings	$3,346	$143,297	2.3%
Hotels, Motels and Housing	$352	$38,356	0.9%
Bridges	$640	$10,209	6.3%
Other	$443	$46,063	1.0%
Single Family Houses	$13	$175,296	0.0%
Total	$4,794	$413,221	1.2%
Total without single family houses	$4,781	$237,925	2.0%

Precast concrete plants serve limited geographic regions, restricted by the maximum distance over which pieces can be economically transported. Although many companies operate more than one plant, the industry remains somewhat fragmented. The approximately 380 plants in Canada, the US and Mexico are operated by some 160 producer companies (PCI, 2001). The elements most commonly produced for building construction are double tees, hollow-core slab elements, inverted tee and ledger beams, spandrels, columns and façade panels. A few companies also produce complete modular building units, such as bathrooms, hotel rooms and prison cells. Despite relative uniformity in the basic section profiles, there is no standard for element dimensions. Each company produces double-tees, for example, with varied basic dimensions. Production of façade panels, termed architectural precast, is technologically advanced. Façade panels offer aesthetic solutions with a complexity of shape and finish usually unattainable in cast-in-place reinforced concrete.

The main competitors of precast are cast-in-place reinforced concrete (CIP) and steel construction. Their relative shares of the market for building structures in 1997 were: CIP concrete: 69%, Structural Steel: 21%, and Precast: 10%[2] (PCI, 2001, Economic Census, 2000, Economic Census, 2001).

[1] The Precast Concrete Products industry (pipes, paving stones, landscaping and garden furniture, etc.) is considered to be separate from the Precast/Prestressed building construction industry.
[2] Some of the figures used in this paper are not comparable. These dollar figures deal with building construction, while the earlier ones deal with all construction.

1.2 IT usage in the precast concrete industry

The precast sector of the construction industry has unique engineering and engineering software needs. However, it has largely relied on mass marketed standard IT products such as AutoCad® or Microstation® for drawing production. There have been intermittent efforts by industry-based software consultants and some companies' IT staff to develop 3D applications on top of various platforms, including Arris®, Autocad®, Microstation® and most recently Solidworks®. These consultants and company IT staff have incorporated special-purpose engineering in the applications, for both structural design of precast structures and for structural design of individual pieces. Also, the Canadian Precast Concrete Institute (CPCI) funded software development for piece design; a number of precast engineering consultants' offices developed semi-automated routines for standard floor layouts within AutoCAD®; one such office developed three-dimensional software for in-house use. Several of the larger precast companies have developed their own applications for internal use, spending in the range of $100,000 annually for these activities. No major software company, however, has addressed the precast concrete market to develop high-end applications.

In areas of information processing other than engineering and detailing, such as contract management, scheduling, rebar fabrication, production planning, materials resource management, and accounting, the industry has mostly relied on general-purpose software. Some companies have integrated their production activities with materials resource planning (MRP) or enterprise resource planning (ERP) packages. Some specialized precast production planning and management systems from Europe have recently made inroads into the US market, such as Elematic's EliLINE® and EliPLAN®.

The lack of dedicated precast engineering and design software with 3D capabilities is in contrast to the steel fabrication and construction sector. Steel construction in North America has a wide range of software applications: for design, engineering analysis, and fabrication detailing and specialized fabrication planning and production. All these software categories include strong 3D functionality and the production-oriented applications facilitate significant production automation. The detailing applications also support some levels of design automation, especially automatic connection detailing. In 1999, the American Institute of Steel Construction (AISC) adopted the CIMsteel product data model to integrate all the applications in its domain (CIS/2 2002). To date, ten 3D applications have working interfaces to CIS/2 (the current version). A growing number of case studies are being presented of the benefits of the CIMsteel interface to reduce design time, eliminate errors and other benefits (Tekla, 2002). Precast concrete producers were aware of these developments and were concerned that they might lose market share from the steel industry initiatives.

The Cast-In-Place concrete (CIP) sector has similarities with the precast concrete industry, with regard to IT and software support. While there are stronger cast-in-place design software applications in Europe, they have not penetrated the US market. The Portland Cement Association has supported the development of some 2D design software of individual columns and beams. Like precast concrete, it too has a number of consultants that have developed plug-in applications on general-purpose CAD packages. Many providers of standard concrete formwork offer 3D design and detailing applications tailored to utilize their formwork solutions; rebar design and fabrication are well served by applications addressing structural design, detailing, estimating and production. Overall, there is little or no integration of data flows across the CIP industry; various applications run on different platforms, with only small levels of automation possible. In contrast, the precast concrete IT initiative appeared to have the potential of gaining market share in relation to cast-in-place concrete.

While providing similar services, these three major providers of building structural systems are quite different in terms of their degree of integration. Steel typically involves separate organizations for design, fabrication and often erection, except in the few cases where a steel fabricator has undertaken design/build services. The cast-in-place concrete business is even further fragmented, often with separate mix suppliers, formwork providers, rebar placement and concrete placement specialties. In contrast, the precast fabricators sometimes have their own batch facility, do their own engineering design and fabrication, and often their own erection. Precast appears to be the most integrated of these three industries, allowing it to gain efficiencies through re-engineering that are not available to its competitors.

1.3 Development of a five year IT development plan

In preparing its white paper for the precast industry, Georgia Tech undertook an analysis of the economic structure of the industry, held interviews with industry leaders and participated in several meetings with industry groups. Throughout the analysis, the lack of 3D modeling software was identified as a major inhibitor to progress. Without good geometric data, little design or production automation was possible. The industry participants established a long-term goal for the work: to move from project initiation to initial production in a week's time (the current time averages four months). The white paper (Eastman and Augenbroe, 2000) included recommendations for a five-year step-by-step development effort including:

1. review of current processes and identification of critical cases affecting productivity
2. development of a specification for advanced capability parametric modeling design and engineering software for precast concrete assemblies and pieces
3. distribution of the specification to software companies, solicitation of proposals for the software development and selection of a vendor, with the goal of gaining a fully supported software product for the industry
4. development of a precast concrete product data model for integrating data exchange within precast concrete plants.

The business case for the plan identified the following objectives:

1. eliminating errors during design, production and erection
2. reducing engineering lead-time to production
3. gaining real-time control as change orders are received and introduced into the design and production cycle,
4. expanding market share by reducing costs and lead-time, in two directions: both within the markets for building types commonly built with precast today, and by extending precast capability to building project types for which precast is not traditionally considered.

However, no basis was available for quantifying these benefits. Rather, they were described in general terms, with example cases provided by both member providers and the research team. The plan had three incremental goals: for the process modeling and critical cases, for the software specification and solicitation, and for development of the product model. It was perceived to be aggressive timewise, aiming to produce both a new engineering application and also an industry product model within a five-year timeframe. It was presented in November 2000.

The original companies accepted the five-year plan and put out a call for collaboration. They undertook forming the Precast Concrete Software Consortium (PCSC), organized as a non-profit limited liability corporation, allowing them to make legal contracts with developers and researchers, while charging members for participating in exchange for later reaping the benefits. The covenants of the LCC were minimal, providing for means of governance, decision making, dropping and adding members. No restrictions were placed on member company actions. Two meetings were arranged with open discussion of the consortium's objectives and expected costs. Twenty-three North American producers eventually joined, as did a number of associate members (primarily precast design and consulting practices).

The PCSC was organized into three different committees. A Technical Committee, made up of senior engineers representing most of the participating companies, was formed to address the technical and production issues of the process modeling and software specification. An Executive Committee was formed to manage the overall effort, and to provide organizational and financial leadership. Final authority was vested in a Board of Directors that included an executive level representative from each of the member companies. The articles of incorporation defined how each of these committees would work. Georgia Tech co-directed the Technical Committee and reported to the Executive Committee. Work on the project officially began in June 2001.

2. PHASE I SPECIFICATION

The initial phase was to undertake the process modeling and identification of important use cases, and also develop a specification for the system architecture and applications.

2.1 Process modeling

Most IT development strategies begin with process modeling. Its primary use is as an instrument to explore, set and communicate the scope of the IT integration envisaged. The effort also enables the participating companies to focus on the more efficient workflows that IT can support; such as eliminating review cycles, providing accurate and instantaneous bills of material, and reducing the accounting effort dealing with change orders. Process modeling also provides a means for allowing consultants to gain an inside understanding of the operations of the industry. Most such efforts focus on developing a single industry-wide process model, typically using IDEF0.

This kind of effort has several weaknesses:

1. It is an expensive and time-consuming committee process, focusing more on committee relations among participants than engaging the managers and planners of operations within participating organizations.
2. It also has low payoff for the participants, with companies naturally resisting describing strategic or innovative workflows because the results are a committee product, without significant company investment or payoff.
3. Because the process model is generic to the industry, it is inevitably high-level, and so does not deal with many of the detailed aspects of design or production that are important in any real world process re-engineering.
4. The information is commonly used to define the scope of IT strategies, used for the definition of applications and for a product model. However, the process models developed often contribute to these activities only weakly, without providing sufficiently detailed and adequate information for application development or product modeling.

The Georgia Tech team initiated a study that tried to increase the benefits of process modeling to those involved. It was based on the following premises:

1. Rather than develop a communal, generic process model, each company would develop its own process model, using a newly developed Process to Product Modeling (PPM) method (see below). This would allow each organization to invest in its own process planning with regard to the new planned technology, and to plan its own strategy for adoption of the envisaged applications and product model as they were being developed.
2. The process models developed by the companies would capture the content of process information flows at a detailed level, providing strong input for later application specification and product model development.
3. A synthesis of the process model information would be used to develop the application specification.
4. New formal procedures would be developed for integrating the information collected in the multiple process models to derive a single product model. It would also be possible to show directly that the resulting product model could support all of the initial processes.

Georgia Tech undertook the conceptualization, design and development of a new method for capturing appropriate information in process modeling to derive a product model. It was called PPM: Process to Product Modeling. PPM consists of two phases; the requirements collection phase and the logical modeling phase. The primary research focused on the requirements collection and modeling method (RCM) of PPM. PPM supports the hierarchical modeling of processes and information flows between activities.

An early version of a tool for collecting individual company models was implemented in Microsoft Visio, and used by fourteen companies to model their existing engineering and business processes (Sacks et al., 2002). The mechanism and the method were implemented in a PPM tool, named GT PPM (Georgia Tech Process to Product Modeling) (Lee et al., 2003). Analysis of the process modeling results revealed a number of shortcomings in the modeling process and tool. An early improvement was the incorporation of automated consistency checking within the tool, which compared the detailed information input and/or output of individual activities with the corresponding input/output of other activities with which they exchanged information (Lee et al., 2002a). Another refinement involved the method for collecting and presenting distinct information items within the GT PPM. A second round of modeling, now including models of the envisaged future processes which would be based on 3D modeling of the precast buildings instead of drafting, was then pursued.

Further refinement of the process and tool were based on ergonomic and complexity criteria, resulting in a step-by-step mechanism to specify and collect information required for each activity within a process. The GT PPM tool (Lee et al., 2002b) is also now in use in other research projects in the construction industry: at Carnegie-Mellon University (concerning the application of RFID technology in precast concrete production), at Purdue (concerning rebar fabrication), and at Teeside University (UK) for modeling the processes of a particular large precast plant.

Initially, there was concern among PCSC member companies about openly discussing their process models in the broad forum of the consortium. It seemed they were exposing their most prized business practice secrets. However, it soon became evident that there were a number of differences in their business models:

1. some producers relied heavily on consultant designer/engineers for engineering services, carrying only a small internal staff and relying on consultants for a significant portion of engineering services;
2. some producers had integrated engineering departments, serving multiple fabrication plants;
3. some producers' business focused on the low-cost efficient production of standard pieces, while others focused on architectural façade panels, which are unique for each project; the latter usually require custom molds for each project;
4. while the Precast Concrete Institute has defined standard pieces and a design handbook (PCI, 1999), the producers initially emphasized the uniqueness of their own products. Despite the fact that, for example, each company made double-tee profiles, a wide variety of product variation existed among the different producers, including different piece designs, special connections, special practices for reinforcing, different practices for prestressing, and so forth; the engineering application and product model would have to support these variations.

In the opening discussions of the PCSC project, the producers emphasized the differences between themselves and other producers. This was motivated by the fear that standard precast pieces, such as double tees, columns and spandrels could be used by architects or developers to design a project and subsequently procure individual precast pieces from different producers, rather than having to procure a whole building from a single producer, as is largely the case today. In this way, they would become suppliers of a commodity rather than build-to-order specialists. However, after development of the process models, the above differences were recognized and changed the nature of discussion, with the observation that each producer had a different niche in the business ecology. Open discussion ensued regarding how different companies dealt with various issues, such as assigning piece marks and control numbers (a piece mark is an identifier associated with a particular piece design, and a control number is the unique identifier assigned to each poured piece.) The discussion regarding process modeling allowed all companies to gain new perspectives on their workflows, and contributed to their developing new workflows based on the new IT technology that was being developed.

In the third phase of the PCSC project – product data modeling – it is expected that process modeling using GT PPM will be the primary method for both requirements collection and logical modeling. Derivation of a logical product model from the information flow contents of a set of process models, using semantic structuring, normalization and/or other techniques, is the subject of ongoing research. Key features are:

- a method to restructure (i.e., decompose and integrate) the collected information into semantic structures that are components of the product model,
- integration mechanisms that compose an overall information structure from component structures,

- version updates of the product model, in response to changes in the processes, such as addition of new types of production or automation that must be integrated, should be facilitated and potentially automated (Eastman et al., 2002).

2.2 Design/engineering software specification

Like many AEC industry sectors, the North American precast concrete industry has been served up to now primarily with electronic drafting. The intermittent efforts to develop 3D and custom applications on top of various platforms, funded by individual companies, has led to the companies recognizing that these are inevitably expensive short-term solutions with large continuing maintenance expenses. The consortium as a group recognized the need and benefits of a strong 3D engineering platform; they would contribute to its development and then commit to its purchase. They wanted a regular product that could be customized to support the individual needs of various companies, regarding their mix of work and varying corporate structures.

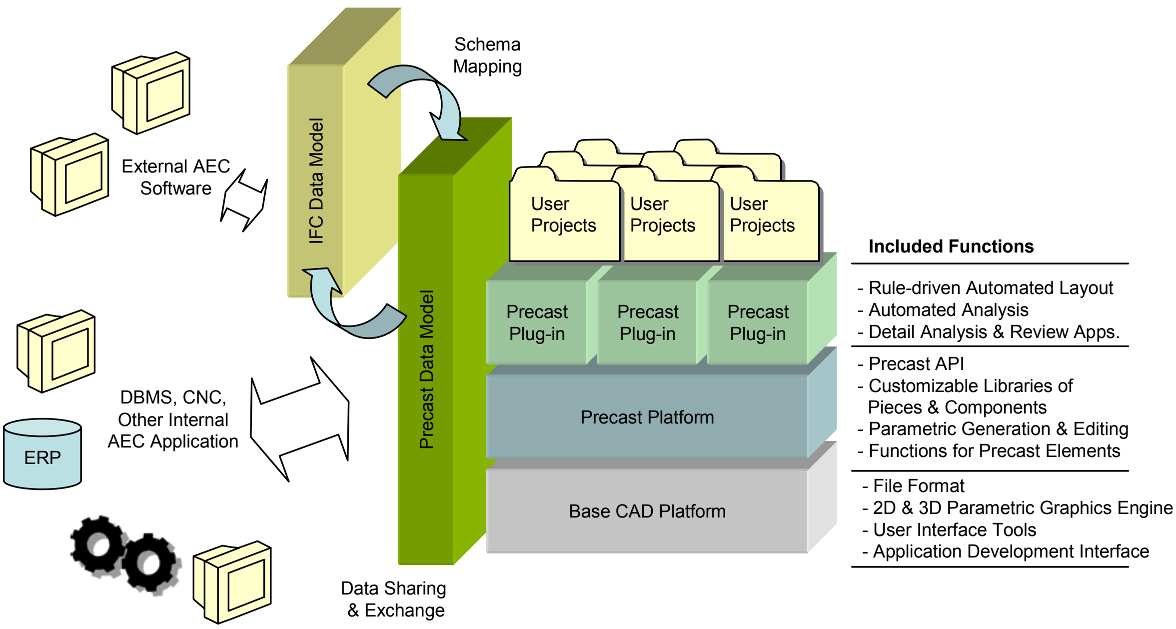


Figure 1: System architecture of the PCSC software specification

The guidelines for the structure and organization of such a platform were developed by Georgia Tech and iterated multiple times with the PCSC Technical Committee to address a range of details. Some of the principle aspects of the specification were:

1. The system architecture to be developed is shown in Figure One. The key feature is an open Precast Concrete Platform. The platform, to be developed on top of a general parametric modeling CAD platform, is intended to provide the geometric modeling capabilities to support straightforward definition of a precast concrete structure, all of its pieces and connections, and the reinforcing and other components embedded in the pieces. It would provide the required geometric modeling, parametric capabilities, and information handling capabilities of the system architecture.
2. The platform is to support the engineering design of precast building assemblies, including whole buildings, such as parking garages or the precast components of an office building.
3. The platform is to support top-down parametric modeling, allowing the full building to be defined as sets of precast assemblies, that could be easily updated and automatically revised. Each of the pieces in the assembly is to be defined, based on its relationship to the overall assembly.
4. The platform must support full fabrication-level detailing of each piece within the assembly (or by itself, if a contract involves just individual pieces).

5. It should support modeling of the interactions (specifically structural connections) between elements of the precast building and building elements modeled in other materials (e.g. cast-in-place foundations, structural steel elements, HVAC systems).
6. The platform must include an open and complete application programming interface (API), to allow plug-in developers to optionally implement automated engineering of the building assembly layout, and also the automatic design of each piece.
7. The platform must support automatic drawing production for all the types of drawings needed by precast producers. This includes assembly and erection drawings, piece, rebar, and mold drawings. These drawing reports must be customizable to the practices of individual companies. It must also support the production of bills of material in various formats.
8. The platform should support interfacing with a precast concrete data model, allowing exchange of engineering data with other corporate information processing applications (see Figure One). The platform must also support import of schedule, BOM and other tags allowing cross referencing, and other information visualization capabilities.
9. The platform must support open-ended user-defined libraries, of standard pieces, standard connections, rebar sizes, finishes, prestress patterns, and other repeatedly used components.
10. The platform was to include a constraint rule checker, allowing easy checking of simple rules such as the maximum size of a piece for shipping, or weight limits for crane movement or erection.
11. The platform must provide reasonable levels of system performance, even with full parametric relationships between pieces and connections that would enable efficient and uninterrupted operation on assembly models with tens of thousands of parts.

These capabilities, packaged to run on a standard personal computer, would not have been possible in the mid-1990s. The movement of 3D parametric modeling from a high-end specialized capability (such as provided in Pro-engineer®, CATIA® and Microstation Modeler®) to a wide range of platforms, and the greatly increased power of personal computers, moving from 100Mh to more than 3Gh, makes it possible for the first time to conceive of modeling building systems with over half a million parametrically structured pieces.

Within the above guidelines, the Technical Committee of the PCSC, with the active participation of senior engineers and IT staff of the member companies, compiled an 88 page specification document (Eastman et al., 2001) over a series of working meetings. While the concepts set out above incorporate some of the basic functional capabilities that characterize existing 3D building modeling software (such as Xsteel and SDS/2 in the structural steel industry), they extend the scope of these 'detailing' packages in that they prescribe full 'design modeling' functionality. The concepts attempt to lay out the functionality envisaged to be needed to support all anticipated levels of future production and design automation desired by any particular producer.

The report formed the basis for a Request for Proposals (RFP). The RFP was distributed to potential software vendors as an invitation to propose a strategy – commercial, collaborative, competitive or otherwise – for their involvement in developing the components of the system architecture, as defined in the technical specification. The RFP included a business section dealing with the contractual issues that would govern the selection process and any eventual development. These included: eligibility of software companies for participation, market potential (number of seats represented in the consortium and estimates for the precast industry as a whole), possible business relationships for a joint development effort (specifically, different models for sharing the inherent risk of investing in the development of new software), and a proposed schedule. The RFP, and the PCSC initiative as a whole, was presented at an open meeting in early January 2002 to 23 software or consultant companies that expressed interest.

The proposals were due by late January, 2002. A website was made available to companies to ask questions and to gain clarification. Twelve proposals were submitted by different groupings of software vendors; some as precast concrete platform developers, some as plug-in developers, and some as consortia of organizations providing both levels of capability. An appendix for self-evaluation by each participating software company detailed a checklist of the proposed functionality of their submission, requiring them to indicate in check boxes whether the functionality was EXISTING, TO BE PROVIDED, or NOT PROVIDED.

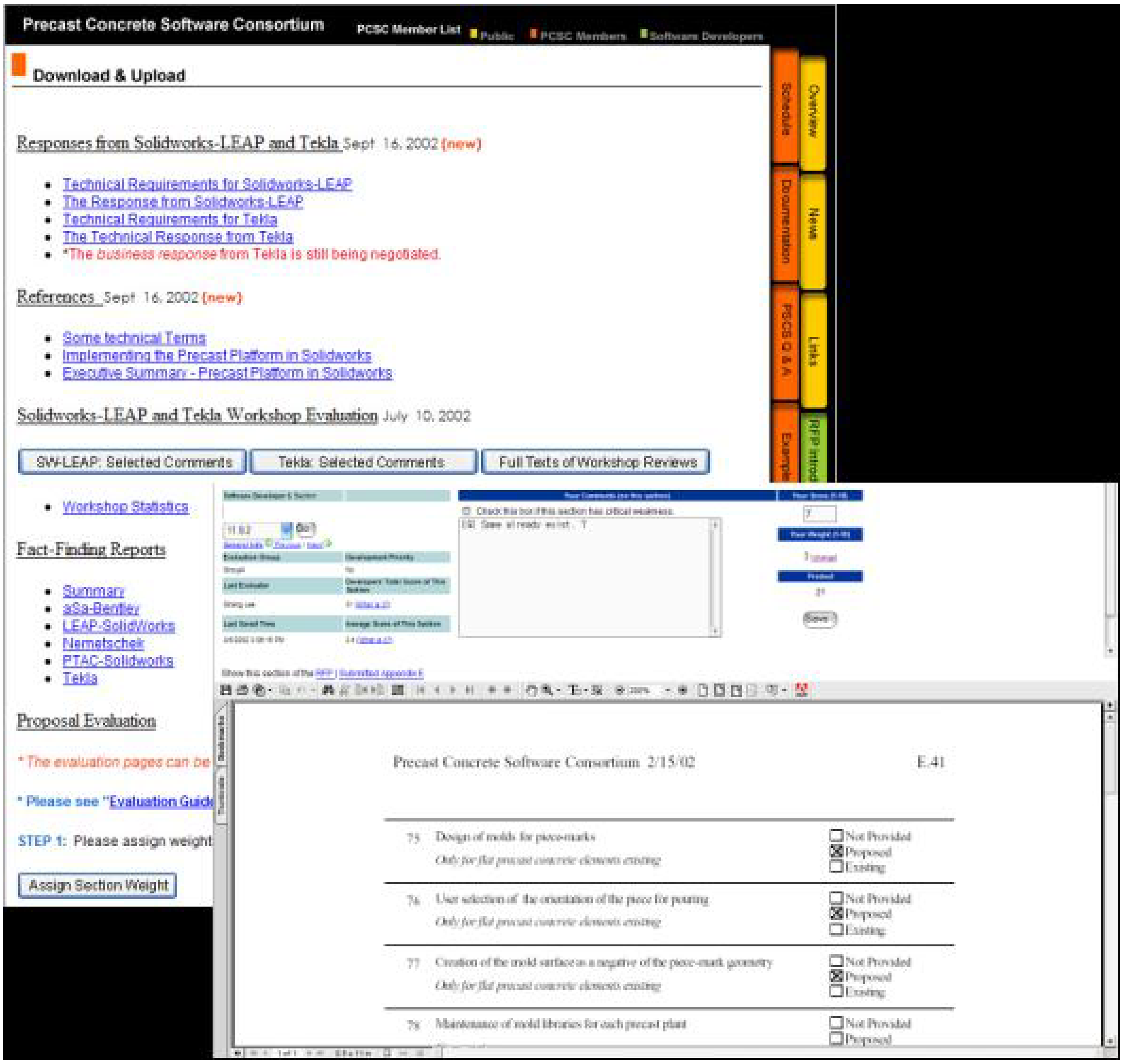


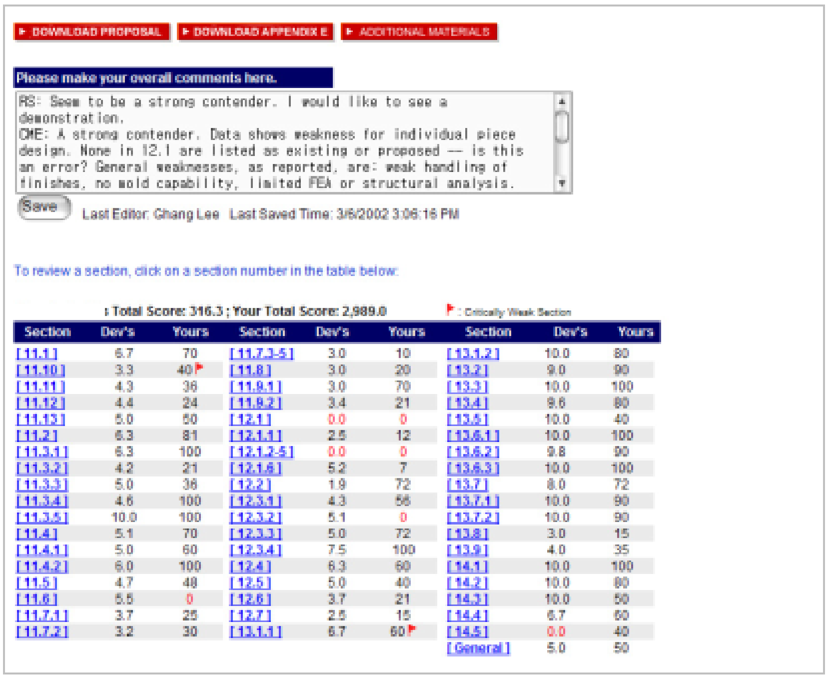
Figure 2: Protected web page submission access

2.3 Software company selection

The proposals were evaluated in three rounds.

The first round consisted of assessing each submitting company's business size, structure and long term viability, and its existing technical capabilities and prospects for carrying out the needed development. The assessment was undertaken through a committee review process that employed protected web-based review documents.

The web pages showed the full submissions of each proposal, as shown in Figure Two. They enabled each member of the Technical Committee to record personal assessments of the proposing company's existing software capabilities (if any), and the likelihood they would be able to provide the requested capabilities, based on their submissions in response to the RFP. Reviewers were asked to express their level of confidence in the supplier for each functional item with a numerical score, and support their ranking by posting comments elaborating their assessment. An example is shown in Figure Three.



Section	Dev's	Yours	Section	Dev's	Yours	Section	Dev's	Yours
[11.1]	6.7	70	[11.7.3-5]	3.0	10	[13.1.2]	10.0	80
[11.10]	3.3	40	[11.8]	3.0	20	[13.2]	9.0	90
[11.11]	4.3	36	[11.9.1]	3.0	70	[13.3]	10.0	100
[11.12]	4.4	24	[11.9.2]	3.4	21	[13.4]	9.6	80
[11.13]	5.0	50	[12.1]	0.0	0	[13.5]	10.0	40
[11.2]	6.3	81	[12.1.1]	2.5	12	[13.6.1]	10.0	100
[11.3.1]	6.3	100	[12.1.2-5]	0.0	0	[13.6.2]	9.8	90
[11.3.2]	4.2	21	[12.1.6]	5.2	7	[13.6.3]	10.0	100
[11.3.3]	5.0	36	[12.2]	1.9	72	[13.7]	8.0	72
[11.3.4]	4.6	100	[12.3.1]	4.3	56	[13.7.1]	10.0	90
[11.3.5]	10.0	100	[12.3.2]	5.1	0	[13.7.2]	10.0	90
[11.4]	5.1	70	[12.3.3]	5.0	72	[13.8]	3.0	15
[11.4.1]	5.0	60	[12.3.4]	7.5	100	[13.9]	4.0	35
[11.4.2]	6.0	100	[12.4]	6.3	60	[14.1]	10.0	100
[11.5]	4.7	48	[12.5]	5.0	40	[14.2]	10.0	80
[11.6]	5.5	0	[12.6]	3.7	21	[14.3]	10.0	50
[11.7.1]	3.7	25	[12.7]	2.5	15	[14.4]	6.7	60
[11.7.2]	3.2	30	[13.1.1]	6.7	60	[14.5]	0.0	40
						[General]	5.0	50

Figure 3: web-based evaluation

The Technical Committee and Georgia Tech reviewed the assessments. All the proposals from Autodesk-related vendors were based on the Autocad platform, which lacks the level of parametric modeling required, and were eliminated in the first round[3]. In addition, it was decided that selection of plug-in developers could only take place after the Precast Platform development was resolved, so the plug-in developer proposals were set aside. After review of the submissions, the original list of twelve was reduced to six, who would receive detailed evaluation in the second round. The short-listed companies were Bentley Systems, two Solidworks-based consortia, Nemetschek, and Tekla. EDS/PLM had made a submission based on Unigraphics® and was short-listed, but dropped out soon afterward because of a difference in business strategy.

The second round evaluation involved more detailed assessment of each submitter's base CAD platform's capabilities, to assess the gap to be filled to reach the requirements of the Precast Platform specification. It included fact-finding trips by the Georgia Tech team to each of the five vendors and review of each company's software development practices, its facilities for providing training and support, and its stability with regard to providing long term support to the precast concrete industry.

The review included running a detailed benchmark test, designed to evaluate the platforms with regard to:

1. parametric behavior, including automatic layout and updating
2. creation, manipulation and change propagation in large and complex models
3. automated production of drawings and other reports,
4. ease of customization and accessibility of its API.

[3] This was a short time before Autodesk's acquisition of Revit®, who expressed early interest but was not represented.

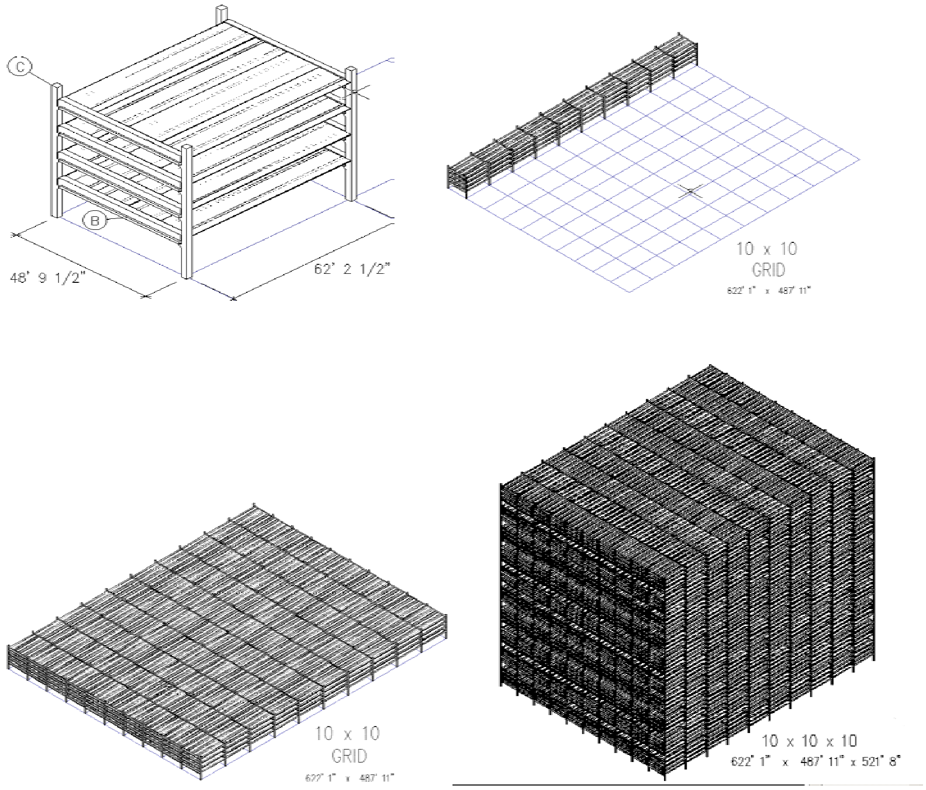


Figure 4: The complexity benchmarking test

The complexity benchmark test consisted of defining three precast elements; a column, an inverted tee beam, and a double tee, as simple piece shapes (no reinforcing or detailing), and then replicating them in ever larger arrays of layouts. The pieces were required to be related to one another and to the overall grid parametrically, such that a change in a grid parameter – such as the width of a bay, or moving one column – would be propagated automatically to the other elements. Both topological and geometrical integrity was to be maintained. At each major increment in replication of the elements, a parametric change was to be made, so that the system's update and regeneration time could be assessed. An example of the models generated is shown in Figure Four. This assessment clarified the ability of the CAD platform to support parametric modeling of very large building models. The hardware configurations of all of the machines used were recorded; the differences in configuration were small, however, as the RFP had determined a maximum overall cost per workstation.

These benchmarks were telling. Some systems could expand the model and carry out the parametric updates effortlessly, while others required minutes to execute them. There were indications that some companies had pre-engineered how to construct the model so as to minimize update times (not uncommon in benchmarks), resulting in a model that was not flexible to other kinds of edits.

After these interviews, the five short-listed companies were invited to make presentations at a workshop in Atlanta in May, 2002. These included live demonstrations of the software benchmark before the full Technical Committee After their presentations, the five short-listed submissions were reviewed, based on the information from the proposals, the site visits and the presentations. Issues in the decision at this stage dealt with the strength of the proposing software companies regarding long term viability, ability to undertake a major software development effort and then to support that product's users, including both end users and plug-in developers. The capabilities of the CAD platform were assessed in terms of parametric modeling capabilities, its support for additional development, both by the main developer and by plug-ins and the ability to scale to large projects. Also considered was the technology base of the CAD platform and its ability to support a complex product over the product's lifetime.

Based on these criteria, the short list was reduced to two proposals, a consortium of Solidworks and LEAP Software, a provider of precast engineering and bridge design software, and Tekla, a Finnish software company well known as the developer of Xsteel. To make a final decision, the two finalist companies were requested to provide a week of training to a set of potential customers, so they would learn firsthand the capabilities of the base CAD platform that would underlie the Precast Platform. They were also asked to present their development ideas for the precast platform. They were asked to re-produce the benchmarks during the training sessions, so that all of the Technical Committee could see and review the results.

The two finalists were very different in their internal organization, in the strengths of their platforms and development capabilities, and their visibility in the US CAD market. The Tekla submission was a precast concrete platform developed by them out of their experience with their highly successful Xsteel product, and their other European products for infrastructure design and management. Its product relies on a proprietary geometric modeling platform, integrated with a database backend. Tekla would provide the complete precast concrete platform, but would rely on outsiders for developing plug-in capabilities. In this case, the distinction between a base CAD platform and a Precast Platform envisaged in the RFP specification (Eastman et al, 2001), was not relevant. Tekla's strength is that they were very familiar with setting up complex assembly-level parametric models that could support detailing of each of the pieces in a top-down fashion. They also had developed a significant portion of the platform, including reinforcing, sample automatic precast connection details, and other aspects of the specification. However, they were not well known to the US market. In comparison, the Solidworks/LEAP submission relied on Solidworks for the CAD platform and on a dedicated precast engineering design software company, LEAP Software, to provide the precast concrete extensions. Solidworks is a well-known mechanical engineering CAD platform, with very general and open capabilities for developing parametric models. Its openness and ease of development is its strength. LEAP Software was the team member that would undertake all the precast concrete platform development, provide the training and interfaces for plug-in developers. They are well known developers of precast concrete piece design and bridge and overpass design packages. A weakness of this second finalist was its high computational overhead, resulting in it not being able to handle the more complex models in the benchmarking test.

There were strong proponents for both alternatives. Some of the member firms of the Technical Committee had previously acquired Solidworks systems and were trying to develop some precast platform level capabilities on top of it. Other members were familiar with Tekla's Xsteel product. The two business proposals were quite different. One proposal included a significant up-front development charge; the other required no upfront costs, but their system's per seat cost was fairly high. The Board considered supporting both alternatives, but the time commitment and costs made this infeasible.

Further tests were run at producer sites, and negotiation on the business aspects of both proposals. After long deliberation, the Technical Committee, Georgia Tech and the Executive Committee recommended the Tekla proposal to the Board and it was accepted by a majority. The recommendation was followed by another training session for interested Consortium members, and a temporary license was provided so that they could demonstrate the Tekla system at their home offices. Some precast producers dropped out of the Consortium, some because of the economic downturn, others because of their commitment to another direction. Currently 13 of the original members have signed up and adopted the recommended solution. New members are being recruited to replace the ones that dropped out.

3. PHASE 2 - IMPLEMENTATION

The original PCSC specification distributed with the RFP (Eastman et al., 2001) outlined functionality; it defined what capabilities were needed, but did not detail how they could be used and combined. Setting this high-level of abstraction for the initial specification document was considered necessary to avoid restricting the precise nature of the Precast Platform that could be proposed. An alternative course that included emphasis on details, such as user interface issues, may have jeopardized the chance of finding an appropriate base CAD platform and developer, due to the relatively small set of potential proposers. Obviously, the specification could not capture the depth of detail required for implementation of a production software system. Instead, the RFP specification called for the joint development of a detailed software design specification (of the first full release of the as yet unnamed precast platform software) by the selected software company and the Consortium. The eventual contractual agreement with the selected company (Tekla) instituted this process; it consists of a four month detailed specification period, to be followed by a one year implementation period for the first release.

In retrospect, the exhaustive evaluation phase described in Section 2.3 had a significant corollary effect, in that it provided informal but in-depth education of the member company representatives of the potential and power of various approaches to parametric 3D modeling. The opportunity to conceptualize what is essentially 'vaporware' in terms of its similarity to, or difference from, existing software greatly facilitated the work of the consortium. In the absence of a detailed specification, it became apparent that the contractual basis for the relationship between the PCSC and the software vendor could be more easily defined in relation to the vendor's existing software than in relation to the original RFP specification. This necessitated additional pre-contract work on the part of all parties to define a 'detailed specification document' that determined both the overall scope of the first release and the enhancements that would have to be made to the existing platform to provide the required basic functionality. The twelve month implementation phase could only commence once the detail specification was completed.

Starting with a relatively detailed outline specification, preparation of the final detailed specification requires fleshing out of the fine details and prioritization of the development sequence. Defining the parametric variables of precast piece cross-sections and library elements is relatively straightforward, but fully defining the parametric behavior of different connection and joint configurations, subject to different possible contexts, is more difficult. It is expected that the objective realities of the limited availability of sufficiently expert resources for doing the specification work will ultimately limit the content that can be included in the first release of the software.

During the implementation phase, quarterly beta releases will be reviewed and commented on by the Technical Committee. Each company will have a pilot user testing and evaluating the system. Both standard product-level and company-specific tests will be used to evaluate progress. A group of advance users will provide a graduated set of tests, initially by duplicating current production work, to sort out problems and missing details. This will be followed by production use on simple projects, backed up by standard CAD support, in case of limitations. This will be followed by increasingly complex projects. The initial production release of the precast platform software is expected to be made by the end of the year. At the time of writing, the four month detailed specification stage is just beginning.

An additional factor considered to be crucial to the eventual success of the Precast Platform is the availability of the engineering plug-in software necessary for analysis and design automation. Participation of plug-in vendors – smaller scale dedicated software vendors active in the North American precast concrete industry – has therefore been strongly encouraged. The intent is that some of their products be fully integrated with the Precast Platform simultaneously with its first release. It was noteworthy that plug-in vendors became involved and agreed to provide plug-in capabilities on the Tekla Precast Platform.

Once the detailed specification of the software is complete, the research focus will turn to development of an elaborated plan for the product data model.

4. EXPERIENCE GAINED

Five years is a long time for any business undertaking requiring significant resources and time commitments. Any five-year development plan, based on industry support, must recognize the extent that external events, such as the business climate, can affect such projects. During the project, several company participants were re-organized or bought out, leading to some consolidation within the industry. The economy went into a serious recession. On the other hand, the progress presented at industry conventions has led to increased interest, and as a result there are discussions to open the consortium to new members.

This example of a successful industry initiative was a result of effective leadership within the precast industry. There was a group of respected industry leaders who had both the foresight to initiate the Consortium's activities, and who were also willing to do the necessary homework to communicate and cajole members, undertake preparation of the needed legal documents, review and meet bi-monthly as the project proceeded. The time and dollar costs of such activities are significant. Each actively participating consortium member donated at least the equivalent of a third of a staff person's time. At the same time, it is critical that the project coordinators (here, Georgia Tech) formulated, then directed the work toward realizable goals. By absorbing broad but detailed discussions of technical issues and generating working drafts of solutions, they were able to expedite the activities toward clear accomplishments well understood by the committee members.

The project maintained its momentum because of several motivations. One was fear of being left behind by the steel construction industry. Another was the clear opportunity to gain market share, with the comparison with European markets being available as an example. These helped carry the group forward in light of the difficulty in providing clear indications of the economic benefits at a time when the parameters of the solutions are still being defined. In such situations there is constant pressure from within the companies to review the economic viability of the ongoing project. There is a tendency to focus on the direct benefits and tangible costs, for example on productivity benefits in relation to seat costs and development expenses, in contrast to the potentially greater indirect benefits inherent in process re-engineering and error reduction, which are harder to conceptualize. Nevertheless, as the proposed systems became more clearly defined, efforts were made to provide clear and reliable economic impact assessment. For example, companies often keep detailed records of errors and changes associated with each project. These can provide important sources of data helpful in developing economic analyses of some of the benefits of high-end parametric modeling systems. During the project, Georgia Tech acquired such information from several companies and was able to estimate the types of errors eliminated with top-down parametric modeling (Sacks et al., 2003). Later, more extensive data was collected; a benchmark for comparing current with future performance was established, and a more comprehensive assessment of the overall economic impact of this part of the IT technology on the precast industry is being prepared.

There was early initial consensus regarding the potential of 3D modeling replacing 2D drafting, for improving productivity, for development of a model-based system able to support accurate bills of material and design and production automation. However, it is at the same time difficult to set aside traditional drafting issues and re-configure them in light of 3D modeling: layer and drawing format issues get replaced with report formatting issues; document-level version control is replaced by object-level version and change management; the perceived need to edit drawings in response to last minute changes, rather than the need to maintain building model integrity. There was also slower awareness of the full impact of such changes to the industry, in terms of the mix of employees, in terms of changing workflows – even though these were frequently discussed. In most cases, the Technical Committee participants were chief engineers of precast companies. Sometimes, drafting department managers got involved in the planning and reviews, naturally raising concerns about job security and obsolescence of current skills. Training and apprenticeship of staff was also an issue discussed. A contract requirement in final negotiations was for the winning software company to donate a number of systems to technical colleges in several regions of the country.

Careful planning with pro-active teams was required to maintain the confidence and movement of the industry consortium. This included setting clear short-term milestones and realizing them. Also, the participants had control of the outcomes. The effort could be undertaken without demanding changes within the breadth of the industry, unlike some multi-country development projects, that have less well-defined industry benefit. Each participating company's benefit was the central objective of the work. The companies could coordinate the development, then purchase and use the technology, with the main dependency being the ability of the software company to deliver. There were no requirements that other segments of the construction industry participate, although the development plans included this as a future option.

Although technology development issues are usually considered separately from business issues, in this type of endeavour, they inevitably become intertwined. At the beginning of Phase 2, an alternative development effort was proposed and some PCSC member firms joined both consortia. This became a business issue because the detailed product specification being reviewed by the Technical Committee was considered to have strong intellectual property value for competing developers. Participating companies were asked by the software company to sign a non-disclosure agreement, which required that they not divulge this information to other organizations. This made each company legally liable for any disclosure, which led to some people resigning from the Technical Committee. The issues of exclusivity of the partnering arrangement and of confidentiality turned out to be important negotiating issues, but were not covered in the LLC by-laws. Also, Tekla could not deal with 12 companies' developing independent requirements; an independent mediator that could structure requirements in software development terms was crucial.

This new kind of detailed relationship between software development companies and an industry consortium provides a model of how a software company can, with much front-end involvement, develop a new platform that is guaranteed to have significant market penetration and endorsement up-front, and with a strong list of initial customers. A number of advantages are apparent:

1. direct access to in-depth, localized and authoritative domain know-how,
2. exclusivity in the market for an initial period,
3. a relatively risk-free stepping-stone towards the expansion of their market to other countries and other AEC markets.

It also provides a possible model for other industry-based initiatives to cooperate on the development of a domain-specific CAD platform. Even though the different companies in the PCSC are often competitors, they saw the benefit of developing a common platform, from which they could customize their software and workflows. The perceived potential to increase market share for all, rather than competition within a fixed size market, was an important facilitating condition.

The steel and precast concrete domain-specific parametric modeling CAD systems are examples of a new generation CAD platform embedding detailed industry-specific knowledge. The next generation of CAD development will be oriented toward development of these very detailed productivity and design automation tools for different sectors of the construction industry.

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