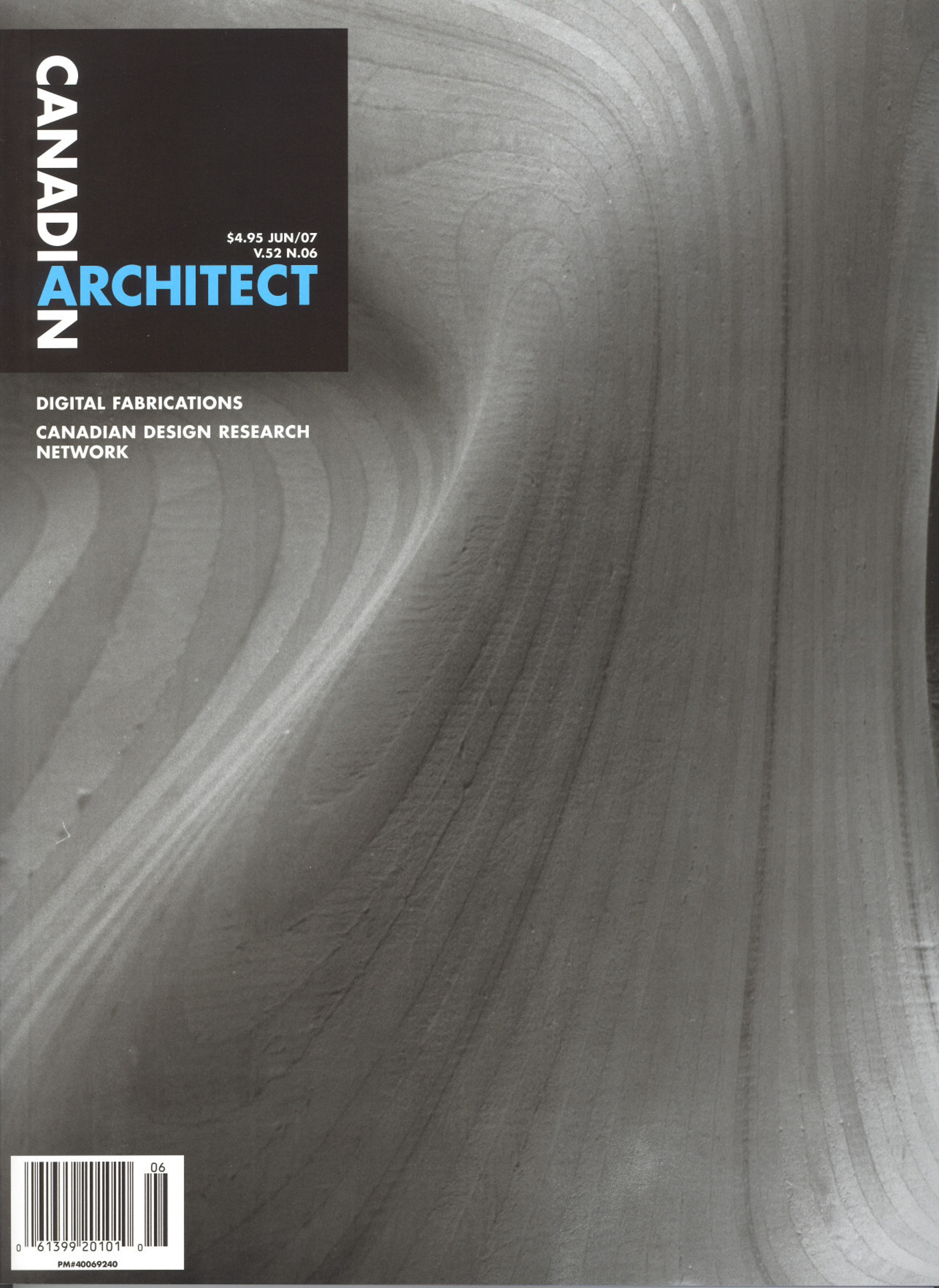

CANADIAN ARCHITECT

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DIGITAL FABRICATIONS

CANADIAN DESIGN RESEARCH NETWORK

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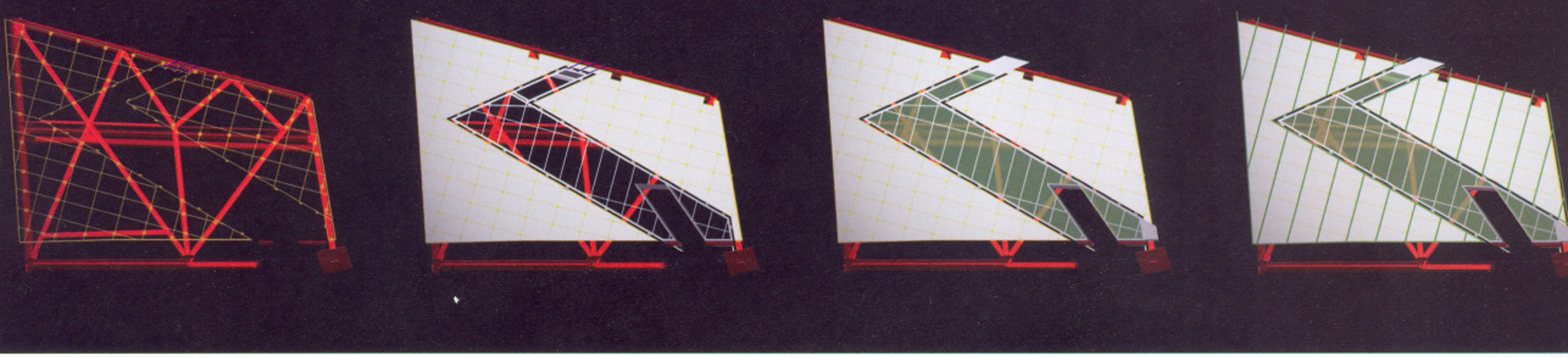
MEASURING FOR SUCCESS



THE TIME HAS COME FOR ARCHITECTS TO INTEGRATE THE METHODS ASSOCIATED WITH DIGITAL FABRICATION INTO THEIR PRACTICES. THIS IS NOT AN ISSUE OF TECHNOLOGY, BUT ONE OF DESIGN MANAGEMENT AND COMMUNICATION.

TEXT IAN CHODIKOFF

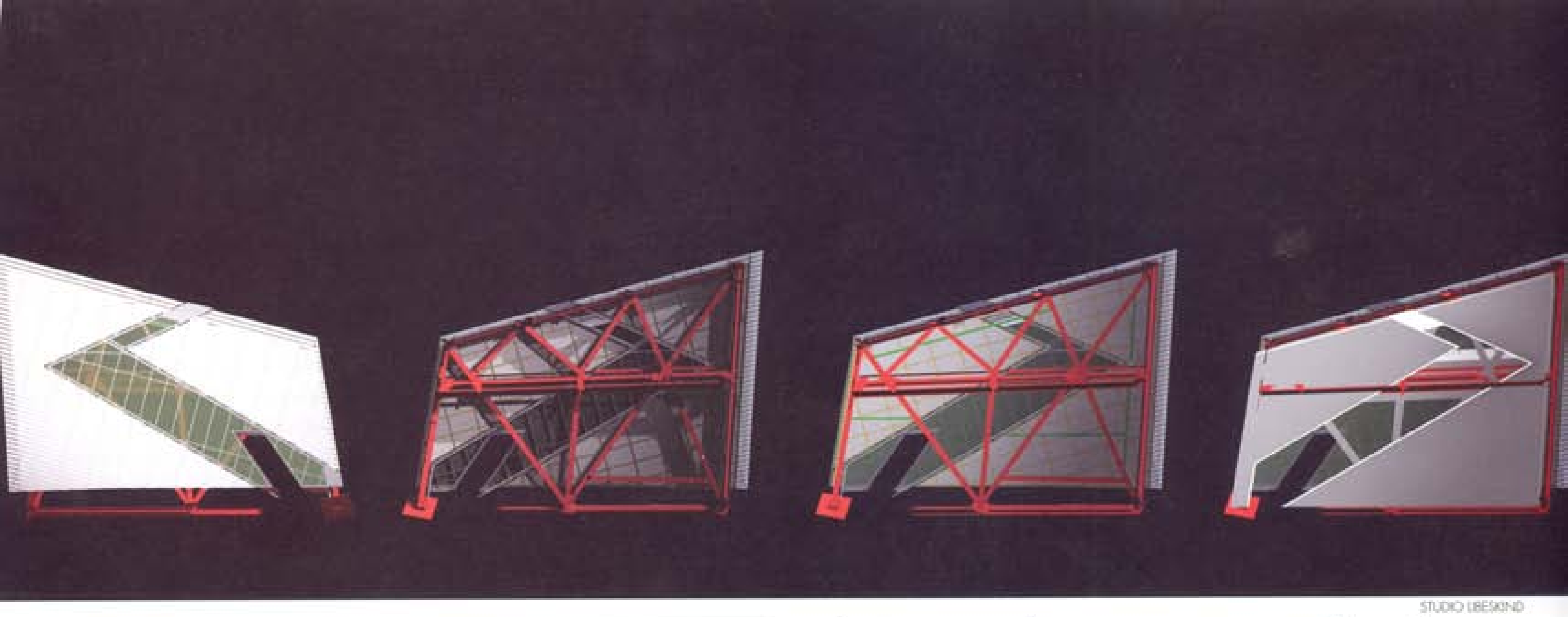
The era of integrating CAD systems into architectural practice is firmly behind us. It is only a matter of time before the makers of AutoCAD will phase out their ubiquitous CAD program and replace it with a more sophisticated software that is better able to catalogue and visualize three-dimensional digital information from conception to construction. Architects need not panic, as they will be able to learn the benefits of maintaining their design integrity while increasing the effectiveness of communicating their ideas to fabricators and contractors. The results will mean transparent budgeting, more efficient installations and a reduction in design and technical information being lost as it moves across the many trades and consultants involved in all project ranges.

Paul Celento's article entitled "Innovate or Perish" found in the Spring 2007 edition of the *Harvard Design Magazine* offers a critical review of why it is necessary for architects to change their existing work habits. Celento argues that a primary source of architects' discontent is that they are often hired to provide custom-design services in a product-infatuated market. Few clients understand what it takes to develop and design a new product and even fewer are willing to pay for it. Fortunately, advances in digital fabrication are creating new opportunities to rapidly create new designs and prototypes, but a large percentage of the profession remains unwilling to explore these new technologies. As Celento argues, "Architects' refusal to embrace technological innovations invites their extinction. Less hidebound professions are ruthlessly shoving their way onto the turf—once the sole domain of architects. The capabilities now provided by furniture system designers, sustainability consultants, construction managers and engineers of all stripes have become so advanced that Martin Simpson of Arup Associates suggests that architects may eventually become unnecessary—except, perhaps, as exterior stylists." To prove Simpson wrong, the following pages will explore the foundations of what a few architects and fabricators are doing to incorporate changes in digital fabrication into their practices.

One of the emerging leaders in bridging the gap between designers and fabricators through digital fabrication is Julian Bowron, President of Feature Factory, a Toronto firm specializing in a variety of custom commissions ranging from exterior signage to specialized showcases and display walls. As Bowron recently noted at a continuing education session held in Toronto last month, the success and future of digital fabrication largely depends on its ability to integrate both the design and construction processes between architects and manufacturers. This has been assisted by the evolution of computer-numerical-controlled (CNC) production techniques, as well as computer software visualization packages like Rhino and 3D Studio Max becoming easier for designers to use. However, it is the parametric solid-modelling platforms like SolidWorks that have really evolved into useful rendering packages, allowing for the sophisticated coordination of shop-drawing packages as well as the ability to maintain a balance between CAD-CAM and craft-based projects.

As Bowron remarks, AutoCAD overtook pencils in the 1980s and computers overtook watercolour renderings in the 1990s. If you couldn't create a computer rendering or fly-through ten years ago, then your client would likely be unimpressed with your creative talents. By 2000, computers overtook semi-skilled labour to the point that we are seeing software packages used in steel fabrication that almost completely automate the entire steel shop-drawing process. Assuming Bowron is correct, by 2010, digital fabri-

ANDREW BORDWIN

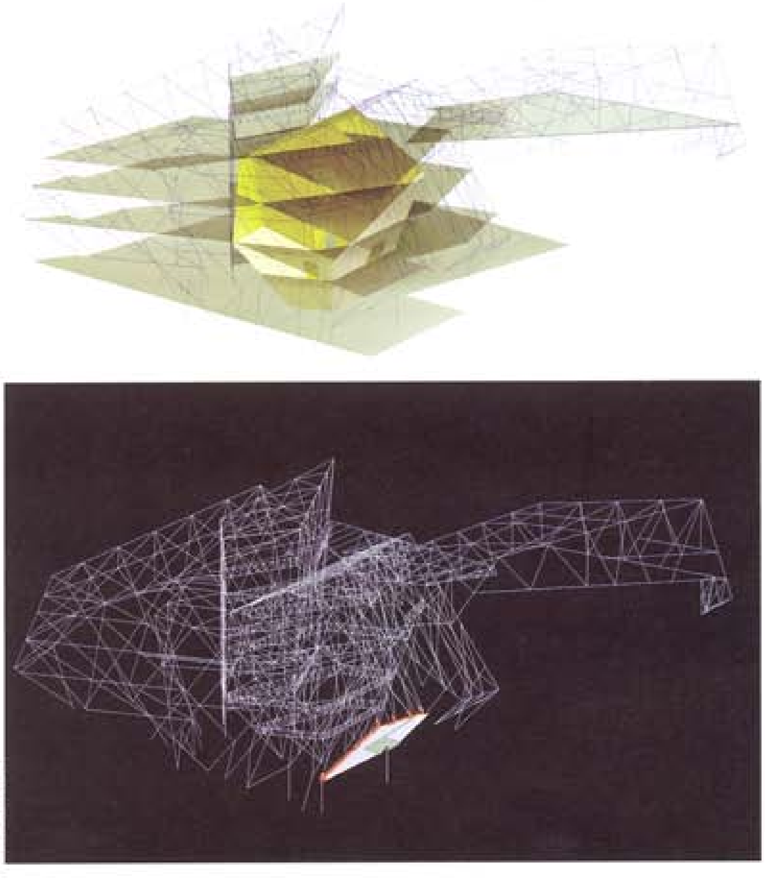


STUDIO LIBESKIND

OPPOSITE TOP, LEFT TO RIGHT A SERIES OF EIGHT COMPUTER MODELS ISOLATING ONE SECTION OF DANIEL LIBESKIND'S CRYSTAL FOR THE RECONSTITUTED ROM IN TORONTO. EACH IMAGE ADDS ANOTHER LAYER TO THE BUILDING'S WALL ASSEMBLY—FROM THE STEEL FRAME, ENVELOPE COMPONENTS, GLAZING AND EXTERNAL CLADDING. RENDERINGS WERE ALSO CREATED FOR EACH ELEMENT OF THE INTERIOR ELEVATIONS. **OPPOSITE BOTTOM** THE HBO STORE IN NEW YORK, DESIGNED BY GENSLER. FEATURE FACTORY IN TORONTO FACILITATED ITS CONSTRUCTION THROUGH THE MANAGEMENT OF DIGITAL FABRICATION. **BELOW** TWO WIRE-FRAME IMAGES OF THE ROM. ONE DEPICTS THE INTEGRATION OF THE FLOOR PLATES WITHIN THE CRYSTAL-LIKE ENVELOPE, WHILE THE OTHER IMAGE IDENTIFIES ONE SECTION OF THE ENVELOPE THAT IS SHOWN IN THE SERIES OF IMAGES ABOVE.

cation will enable innovative built form to be completed in an era of diminishing skills, as graduate architects continue to work in offices with minimal knowledge of how assemblies are constructed, and as the companies that build your designs hire increasingly unskilled labour.

Parametric solid modelling was initially developed for industrial design applications in an era where computers were not powerful enough to conceive the design of entire buildings—never mind complex buildings designed by the likes of Norman Foster or Frank Gehry. As the cost of computer power decreases and software improves, the realism, size and complexity of modelling increases. Currently, software systems have the ability to incorporate spreadsheets and scheduling modules to create Building Information Modelling (BIM) systems that can accommodate a variety of computer file forms useful in all stages: conception, modelling, analysis, detailing, cutting, assembling, installing, and even maintaining building materials. Parametric solid modelling is a highly efficient system for creating, organizing, and viewing large amounts of data, simplifying contracts, reducing the number of change orders and speeding up construction. However, it is the ability to manage data while ensuring a 3D image in the designer's imagination that is the overarching advantage in successful parametric modelling, leading to seamless digital fabrication.



STUDIO LIBESKIND

The issue of data management is evident with firms like Soheil Mosun Ltd.—a Toronto firm specializing in a variety of fabrication techniques involving everything from steel and glass to wood and stone. Like Bowron, Soheil Mosun's CEO Darius Mosun might typically receive a fax from a contractor who pulled a drawing off a tender package to bid on a job. With dimensional information and the architect's concept missing, a fabricator will have difficulty determining whether or not he is supposed to build a steel object that is intended to glow, or support a tank in the basement. This is a clear example of data being lost—the design concept fails to be communicated to the actual people who are constructing the building.

So what does the future of parametric solid modelling actually look like? It looks more real where shadows, light qualities and optical properties of acrylic or glass can be accurately depicted—and thus anticipated—in model form before fabrication can begin. It can also shorten timelines—a valuable benefit for any client. In the case of Grip Limited, a Toronto office interiors project completed by designer Johnson Chou, digital fabrication allowed 84 workstations to be designed, manufactured and installed within five weeks. It took one week to design the prototype, three weeks for fabrication and one week to assemble the units. By using a digital modelling process where every part is conceived—down to a single flat-head screw, a bill of materials is compiled, giving an accurate account of what needs to be priced and built.

Bowron's firm manufactured the Grip workstations, and he explains that digital modelling allows the architect to view, rotate, measure and hide specific elements of the design to see how the various components relate to each other before a single piece of metal is cut. From a software-modelling program like SolidWorks, a designer can generate file formats (i.e., DXFs) that instruct a machine to do the cutting—such as a shuttle table laser. For the Grip project, Bowron sent a crew of installers to the site with rechargeable drills, just in case any manual adjustments had to be made with respect to the holes needed to lock the workstations in place. Of the 84 workstations manufactured, not a single hole was reamed in any way whatsoever—there were no manual adjustments to the design.

Another interesting project executed by Bowron was a chandelier installation designed by Yabu Pushelberg for a hotel in Miami. The construction of the chandelier initially considered custom-fabricated ceramic tiles. However, the cost and time frame involved was prohibitive. Therefore, Bowron designed and modelled a tile prototype that would be machined on a gantry router, and then manufactured in plastic using a vacuum-forming technique. The tiles would subsequently be assembled on a very simple aluminum frame. The final cost of the chandelier was one-sixth of what it would have cost if the tiles were ceramic.

With digital fabrication, it is also possible to create assemblies that are highly detailed in theory and in practice. The communication breakdown occurs not only between the designer and fabricator, but between the fabricator and the installation crew. The Moët Hennessy offices in New York, designed by The Phillips Group (TPG Architecture), is an example of how Bowron's firm was able to coordinate a cost-efficient installation. Because Bowron anticipated a relatively unskilled crew, he had a 250-foot-long plot printed out and affixed to the floor of the job site so that the crew could simply screw the drywall track directly to the layout. When the installation was complete, the first panel split the line on the drawing at the beginning and the last panel split the line on the drawing at the end. And while the total installation budgeted was $30,000—and accepted by the client—the actual cost came in at $6,800, allowing the contractor to walk away from the job with a tidy profit.

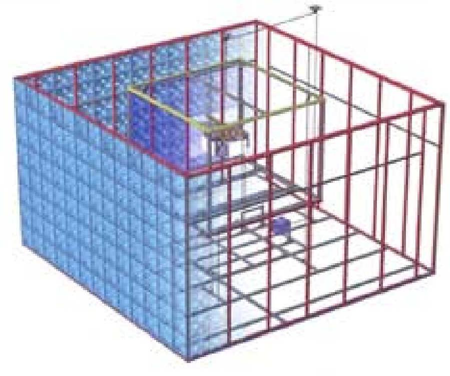
A similar anticipation of where low-skilled and highly paid labour issues can be circumvented occurred in the new HBO store designed by Gensler. To complete a design where there would be no visible fasteners, Bowron needed to undertake extensive digital prototyping (in addition to conducting in-house material testing) and create a detailed installation guide complete with rendered views and step-by-step instructions that would make the minds behind Ikea assembly instruction booklets green with envy. Explicit instructions were a necessity, as time was a premium—given that the job had to be done at night. With the going rates for overtime labour set at US $200/hour with at least an

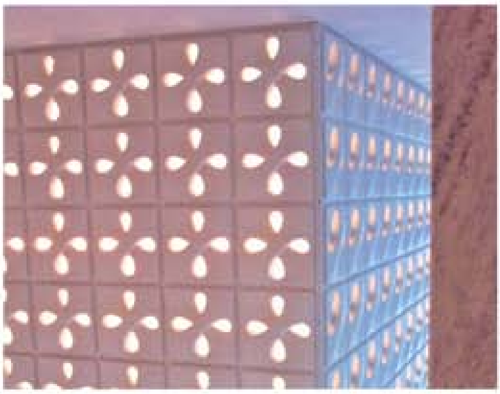

ANDREW BORDWIN

ANDREW BORDWIN

TOP AND MIDDLE JULIAN BOWRON DEVISED A DETAILED INSTALLATION PLAN TO SAVE ON LABOUR COSTS AND TO ENSURE THE ACCURATE CONSTRUCTION OF THE NEW HBO STORE IN NEW YORK, DESIGNED BY GENSLER. **BELOW, LEFT TO RIGHT** A NEW CHANDELIER FOR A HOTEL CALLED MIAMI ONE WAS EXECUTED BY BOWRON, WHO MODELLED A PROTOTYPE FOR A 3D TILE TO BE MANUFACTURED IN PLASTIC, THEN PAINTED TO LOOK LIKE A CERAMIC TILE; THE ASSEMBLY WAS MOUNTED ONTO A SIMPLE ALUMINUM FRAME; THE COMPLETED CHANDELIER WAS DESIGNED AND BUILT FOR A FRACTION OF WHAT IT WOULD HAVE COST HAD THE TILES BEEN MANUFACTURED IN CERAMIC.


FEATURE FACTORY



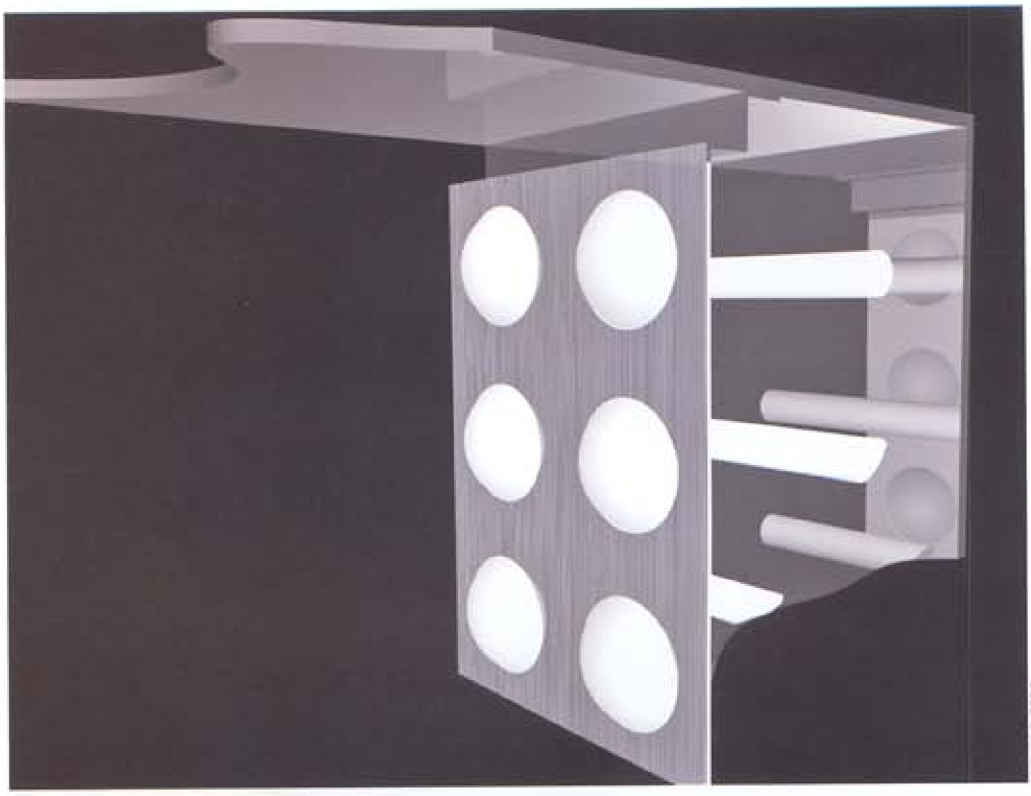

FEATURE FACTORY

eight-man crew and a four-hour minimum call, there was no time to lose.

Like Bowron, Mosun's design team engages at all levels of a project's development, and with a variety of stakeholders. Owners, developers, architects and designers routinely visit Mosun's office to clarify budgets and enhancements to their projects. This dialogue is necessary to understand how a fabricator uses digital information—for both traditional and computer-assisted machinery. By establishing a studio environment where designers can come in and see how machinery is used on everything from architectural metals, glass, solid wood, wood veneer and acrylics, designers can see for themselves what kind of detailing they can develop, and what the capabilities are of material interfaces achieved through mock-ups and prototypes. It is no secret that a lack in drawing clarity will leave considerable room for interpretation—often to the detriment of a project's success. By reorganizing their offices to create a studio workspace that fosters ongoing collaborations and relationship-building across a range of designers and architects, Mosun intends to make the constantly evolving technology easier to swallow and more effective for all concerned.

The Bahá'í Temple for South America, Santiago, Chile

This story would not be complete without at least some discussion surrounding the Bahá'í Temple in Santiago by Hariri Pontarini Architects (HPA). Justin Ford, an associate with the firm, is the digital fabrication point man for the project. The "Temple," as it is commonly called, presented a huge learning curve for HPA, who didn't expect to invest so heavily in digital fabrication techniques when they initially won the competition in June 2003. For HPA, being conversant in digital fabrication was important—if they didn't do it, then somebody else would. BIM technologies provided an incredible tool to design and resolve the development of the project. The simple brief for the Temple—a nine-sided dome with nine entrances—allowed a lot of dreaming to occur for the HPA design team. They eventually arrived at a main structure comprising three elements: Spanish alabaster and cast glass with a highly engineered steel structure sandwiched in between. Modelling the process, both by hand and through the computer, afforded the team a considerable opportunity to explore form and function.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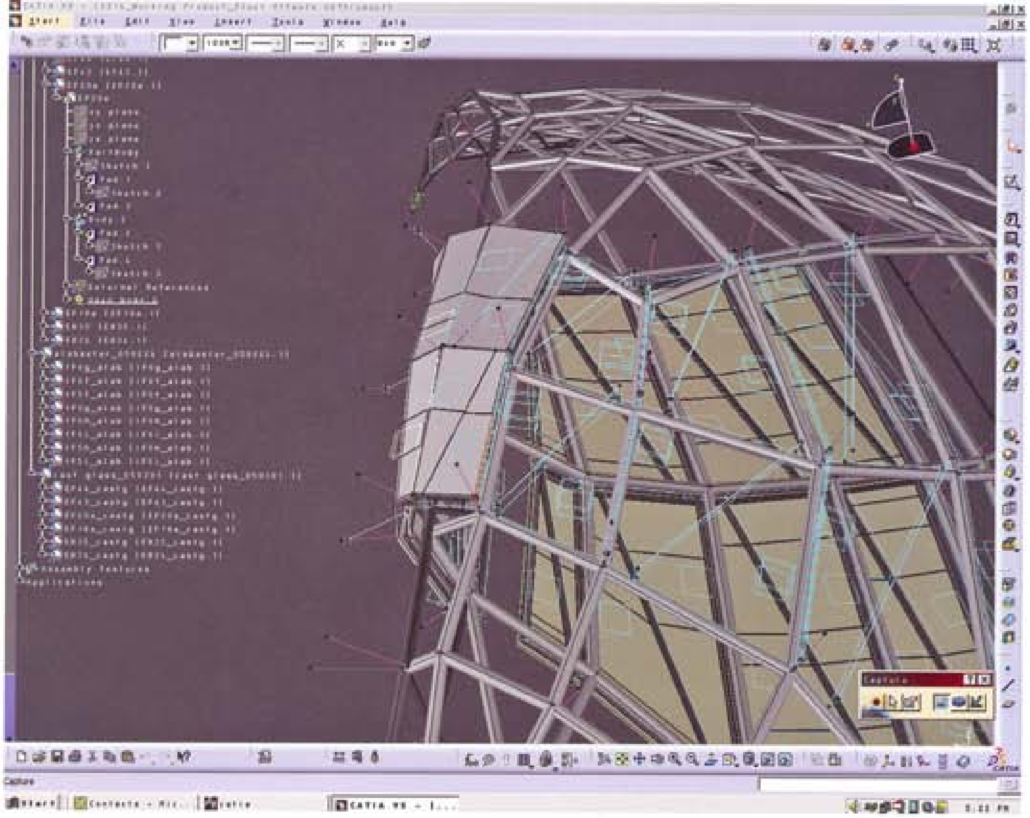
ADRIAN WILSON


ADRIAN WILSON

RIGHT, TOP TO BOTTOM A SOLID COMPUTER MODEL OF A SECTION OF THE PERFORATED CURVED METAL WALL INSIDE THE MOËT HENNESSY OFFICES IN NEW YORK, DESIGNED BY TPG ARCHITECTURE; TO ENSURE AN ERROR-FREE INSTALLATION, THE 250-FOOT-LONG WALL WAS CONSTRUCTED USING A TEMPLATE AFFIXED TO THE ROUGH CONCRETE FLOOR; THE COMPLETED OFFICE SPACE USES A VARIETY OF INTERIOR LIGHTING STRATEGIES TO DEFINE ITS VARIOUS PROGRAMMATIC REQUIREMENTS.



HARRI PONTARINI

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TOP LEFT THIS SCREEN CAPTURE OF A MODEL—GENERATED WITH CATIA SOFTWARE—DEPICTS ONE OF THE LEAVES TO BE FABRICATED FOR THE BAHÁ'Í TEMPLE. **LEFT** A RENDERING OF THE TEMPLE, ILLUSTRATING THE STEEL FRAME BEHIND THE TRANSLUCENT ALABASTER. **ABOVE** A FIVE-AXIS MILLING MACHINE CARVES OUT A SELECTED CATIA-GENERATED ELEMENT OF THE BUILDING OUT OF ALABASTER; COMPLETED PIECES OF ALABASTER STONE MILLED WITH ABSOLUTE PRECISION.

HARRI PONTARINI

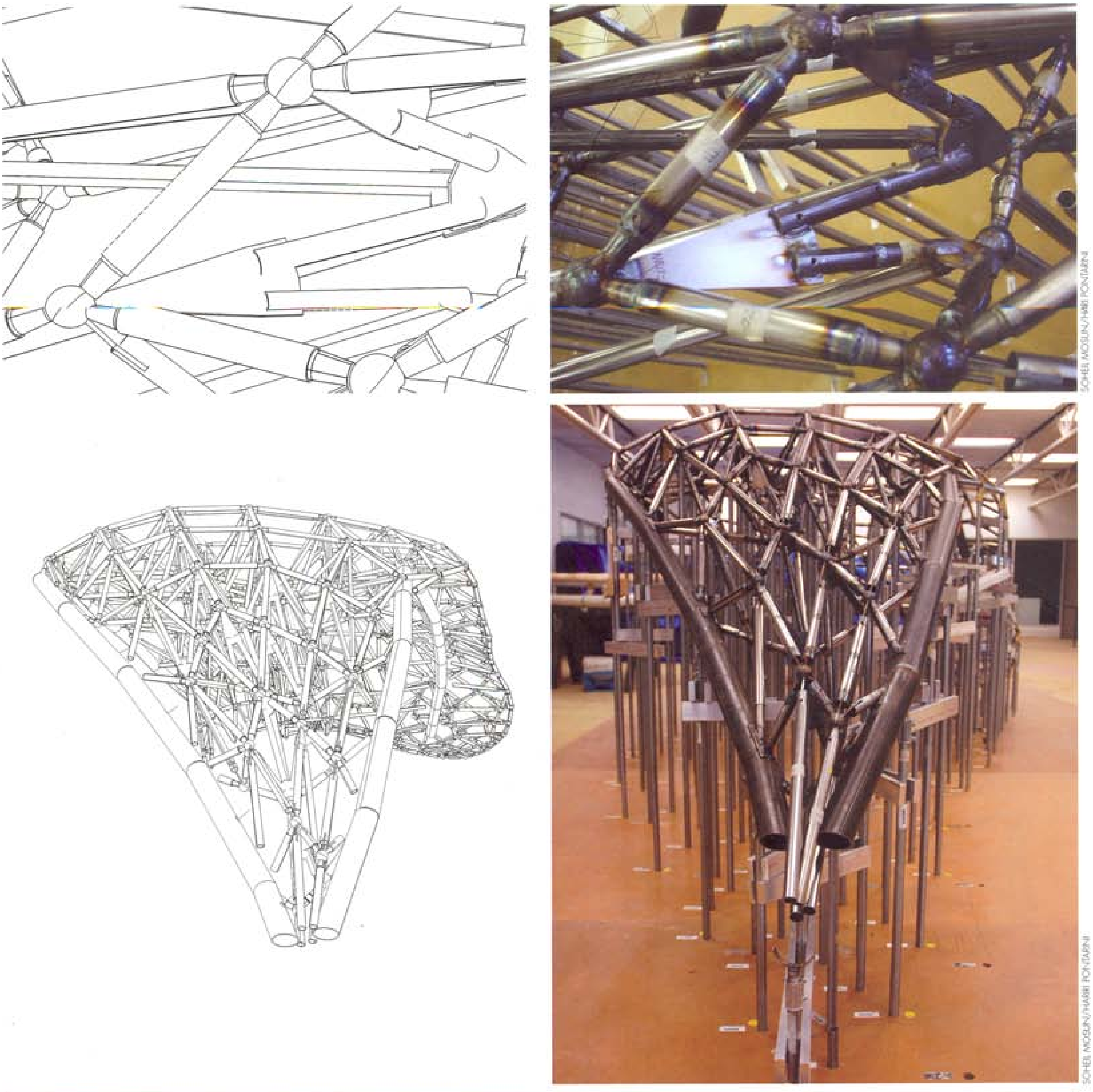
Computer modelling was initially developed through MAYA—a software package typically used in the animation industry. Its major drawback is that it doesn't ascribe specific units to the model. Building from an abstract digital sculpting tool was not going to be sufficient. At this point, HPA discovered the complex aerospace design software program called CATIA. Using a special plug-in for CATIA called Digital Project that was developed by Gehry Technologies, HPA was able to use the program to accurately model and dimension the various components for the Temple, thereby rationalizing the nine leaves comprising the dome.

As the project has developed, HPA has undertaken the construction of a 1:6 prototype of one of the Temple's leaves so that they could establish a realistic pricing schedule for the steel structure. Working with Darius Mosun's team of designers and fabricators at Soheil Mosun, the model created the necessary jigs to fit all the pieces together and even anticipated the space required for a welder to go in and work on the steel structure. For the stone cladding, HPA was able to mill various pieces of alabaster for the project with a five-axis CNC milling machine. Referring to the individual pieces of stone with names like "bullnose," "shoulder" and "spine," it was important to catalogue each of these exterior stone elements as the design studies progressed, leading to the elimination of unnecessary shapes in the eventual construction of the project.

For the mock-up of the steel structure, HPA worked with Soheil Mosun to model, fabricate and catalogue each of the steel plates and tubes required for the structural system of the Temple—keeping track of the changes along the way. Because of the current state of construction which still relies primarily on two-dimensional drawings, and because most bidders and builders do not use CATIA software, HPA had to convert some of the information contained in the model to an AutoCAD drawing, dressing the information up with the requisite gridlines, section cuts, dimensions and other various notations. The back-and-forth process of either working from three to two dimensions, or from technology- to craft-based design was essential in verifying the desired effects of the design concept, while ensuring that the project could be built as planned.

The Michael Lee-Chin Crystal in the new ROM, Toronto

Another example of using digital fabrication to manage a design concept to completion is at the "renaissance" of the Royal Ontario Museum (ROM), designed by Daniel Libeskind. One of the first steps that Studio Libeskind took after winning the design competition for the ROM in 2002 was to develop a model in form-Z before working in physical models at various scales to reconcile the programmatic requirements of the project. The overall structure is basically a diagrid—giving the "Crystal" element of the ROM's renovation multiple load paths and allowing the architects to eliminate a number of interior columns. Computer studies were also taken to a level where floor plates could be manipulated so that the internal openings would make sense and that sprinklers, rainwater leaders and other



SOHEIL MOSUN/HARRI PONTARINI

SOHEIL MOSUN/HARRI PONTARINI

ABOVE A 1:6 MOCK-UP OF THE STEEL STRUCTURE INCLUDING ALL CONNECTIONS FOR ONE WING OF THE BAHÁ'Í TEMPLE HAS BEEN FABRICATED AT SOHEIL MOSUN LIMITED IN TORONTO. SHOWN ARE COMPARATIVE IMAGES OF THE COMPLETED PHYSICAL MOCK-UP AND THE CATIA VIRTUAL MOCK-UP.

building components would not conflict with the new structure and building envelope. With a digital model in place, the construction of the "Crystal" involved a series of X, Y and Z coordinates that Vanbots, the construction manager, could use to pinpoint various key structural elements. These points in space were necessary to survey so that the intersecting planes of each element of the façade could be adequately built. With the exception of the steel and façade contractors, very few of the trades were able to work in three dimensions.

The Future is Now

There are a variety of options available to architects and engineering firms as they continue to explore parametric solid modelling and digital fabrication techniques. Incorporating digital fabrication into mainstream practice will not be resolved by simply throwing money into new software and equipment, but it should be undertaken as part of a dialogue that begins with better communication amongst architects, fabricators, construction managers and contractors. Architects will remain the ultimate coordinators of their design projects, and should not be fearful in advancing their firms' capacities to visualize and model their designs, ensuring a greater level of transparency and clarity in the tendering of future projects. Through digital fabrication techniques, information can be better managed. And as a result, fewer pieces of information will be lost in the design process—resulting in better buildings that are able to push formal boundaries that would otherwise not be possible. **CA**

DIGITAL FABRICATION: THE MACHINERY

Architect and University of Waterloo architecture professor Philip Beesley provides a few pointers for firms who are interested in purchasing digital fabrication equipment. Beesley, who looks at digital fabrication as an automated construction and design approach, explains that the cost of investing in 3D printers has dropped significantly over the past few years.

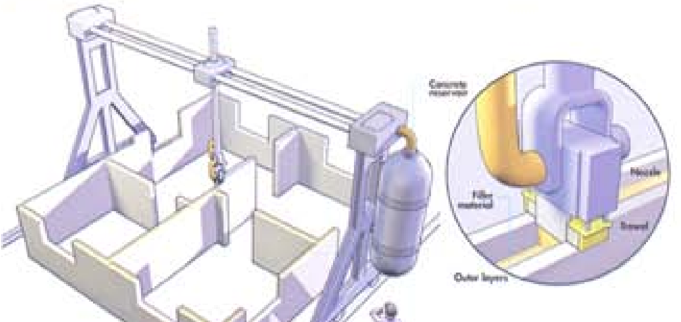
The two primary types of digital fabrication machines are cutting machines and fused deposition 3D printers. Cutting machines comprise laser cutters—primarily for cardboard, acrylic, plasma and water-jet cutters—whereas fused deposition machines rely on a form of starch which is secreted layer upon layer, often infused with a chemical hardener such as cyanoacrylate (a version of Krazy Glue). Another form of three-dimensional printing involves a milling machine which typically operates in three axes: X, Y and Z. Two additional axes can also be added for what is considered a five-axis milling machine achieved through a tilting machine and rotating table, allowing for undercutting and more complex forming.

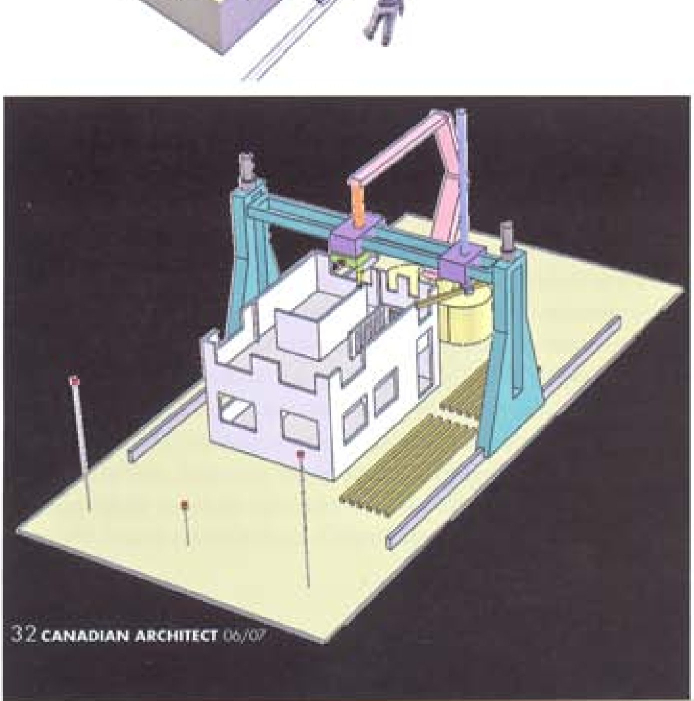
Lightweight milling machines can range from $3,000 to $10,000. Industrial laser cutters, as well as heavy-duty milling machines can cost anywhere from $300,000 to $500,000, but this equipment will usually be found in fabrication shops. For architecture offices who want to make presentation models, laser cutters can range from around $9,000 for a used model or up to $30,000 for a brand-new one. Desktop versions—which have a smaller wattage and printing size capacity—can be purchased for less and are well suited for simple and accurate cardboard or acrylic models which contain a high degree of detail. A relative to the laser cutter is the plasma cutter. Similar to a plotter, it uses a gantry with a cutter that can cut through steel. Water-jet cutters are able to slice through thick aluminum plate or Corian countertops, but this type of equipment would realistically be used by the fabricators, and would not be found within an architecture firm. In terms of accuracy, stereo lithography is more accurate than the fused deposition method of building 3D models made with hardened cornstarch. Using a fused resin within a resin bath, stereo lithography involves two lasers that focus on a specific point of the liquid resin, hardening the material and producing a prototype with a high degree of accuracy.

As far as the future is concerned in terms of equipment, there are some very ambitious projects on the horizon. Behrokh Khoshnevis, an engineering professor, Director of the Center for Rapid Automated Fabrication Technologies (CRAFT), and Director of the Manufacturing Engineering Graduate Program at the University of Southern California, is developing a process to print entire buildings. Extrapolating on the idea of a fused deposition printer, Khoshnevis is experimenting with a truck and gantry-type apparatus that deploys a special concrete that "prints" a concrete foundation, then adds the walls, and places beams and lintels into place with a robotic arm. A special tooling process would ensure that everything is kept level and trim as the walls rise up. Khoshnevis expects to see single residences and community buildings built this way by 2009, along with infrastructure like waterworks and electrical conduits being "printed" sometime thereafter. It sounds ambitious, but the way digital fabrication technology is headed, it will only be a matter of time before more construction techniques are automated.

PETER TESTA

LARRY SASS





BEHROKH KHOSHNEVIS

TOP LEFT A PROTOTYPE HIGH-RISE TOWER USING A SPIRAL TUBULAR DIAGRID STRUCTURAL SYSTEM OF INTERWOVEN CARBON-FIBRE STRANDS WOULD BE CONSTRUCTED BY EXTRUDING A QUICK-SETTING RESIN AND FIBRE MIXTURE. **MIDDLE LEFT** A PLASTER MODEL IS SHOWN BEING EXTRACTED FROM THE BUILD CHAMBER OF A ZCORP FUSED DEPOSITION MODELLER—THE MODEL USES INEXPENSIVE PLASTER AND STARCH POWDERS, WITH PRINTING MECHANISMS SIMILAR TO INK-JET PRINTERS. **BOTTOM TWO IMAGES** THE THREE-DIMENSIONAL PRINTED HOUSE, A CONSTRUCTION SYSTEM IN DEVELOPMENT BY BEHROKH KHOSHNEVIS THAT WILL EVENTUALLY PRINT ENTIRE HOUSES. USING A COMPUTER-CONTROLLED NOZZLE MECHANISM, A MOVABLE GANTRY SYSTEM EXTRUDES QUICK-SETTING LIGHTWEIGHT CONCRETE SLURRY, THEN SHAPES IT INTO FINAL SURFACES. A DETAIL OF KHOSHNEVIS'S PRINTED HOUSE ILLUSTRATES A ROBOTIC ARM PLACING CONCRETE AND LINTELS WITH THE AID OF LASER-GUIDED LOCATION POINTS.