Automated Rule-Based Building Design and Engineering at Robertson Ceco Corporation

AECbytes "Building the Future" Article (June 16, 2005)

Both the recent AIA TAP conference and the AIA National Convention held last month (captured in AECbytes Newsletters #21 and #22 respectively) were evidence to the fact that we are slowly but surely moving away from drawing-oriented CAD technology towards model-oriented BIM technology. The discussions at the technology-specific AIA TAP conference were no longer focused on making the case for BIM but were instead centered on how to speed up BIM implementation. And at the AIA National Convention, BIM was pushed right to the forefront of professional practice by making it the focus of a panel discussion, which was the theme presentation for the general session on the second day of the conference. The resounding message that this discussion sent to the broader professional audience was that if we don't get up to speed on this technology, we will soon be out of business.

In sharp contrast to how most of the AEC industry is just waking up to the potential of BIM and taking baby steps towards implementing it, there are those who have already gone well beyond BIM. I had made a reference to one such effort in my feature article on prefabrication in Norway, where I described how the Selvaag Group, a leading house developer in Norway, uses a model-based specialized application for housing design. Referred to as RDBH (Rule Based House Developer), this system captures housing design rules and domain knowledge to automate different aspects of design: generative rules are used to automatically create a detailed design from a conceptual model, while evaluative rules are used to check the designs for the satisfaction of specified criteria and constraints. Another example of the use of a similar rule-based system is by Robertson Ceco Corporation, the third largest manufacturer of pre-engineered metal buildings in the US today, which is using it to automate its design and engineering tasks. Coincidentally, or not, both of these systems are powered by the same application, Design++, a knowledge-based modeling solution developed by Design Power, Inc. Examples such as these are indicative of the future potential of BIM, when it goes beyond simply being a medium to document the design and plays an active role in the actual design generation process.

This AECbytes feature article studies how Robertson Ceco Corporation has used the rule-based technology of Design++ to automate its design and engineering tasks and the impact this has had on its business. Let's start with a brief look at the firm and the pre-engineered metal building industry.

Overview of Robertson Ceco Corporation

Robertson Ceco Corporation (RCC) is part of the $2.7 billion Heico Corporation, a privately owned holding company. It comprises three companies that manufacture pre-engineered metal buildings for the industrial and construction industries: Ceco Building Systems, Star Building Systems, and Robertson Building Systems. It operates six manufacturing facilities in the US and one in Canada. The size of its buildings ranges from under 150,000 sq. ft. to up to 1 million sq. ft. and up to four stories high. It had sales of over $400 million in 2004 and is ranked as the #3 supplier of pre-engineered metal buildings in the US today.

Metal buildings as an industry dates back to the early 1900s. It started off with the production of small metal buildings for use as garages, tool sheds, and "dog houses" (small portable buildings located near oil field derricks to shelter men and equipment). For instance, the oldest RCC company, Star Building Systems, was formed in 1927 to meet the needs of oil drillers in the historic Oklahoma City oil boom. It moved on to build warehouses and aircraft hangers for military needs in the 1940s, and utilitarian warehouses and grain storage buildings in the 1950s. The metal building industry got a big boost in the early 1960s with the advent of computer designed rigid frames, high yield steel, and factory-applied, baked-on color coating on steel panels. It led to the emergence of the "pre-engineering" concept, when manufacturers would design, detail, and fabricate a defined group of standard buildings of set widths, heights and loads. Any customer who wanted a building would choose a specific combination from the selection set offered by the manufacturer: for example, 24 widths, 6 heights, 3 bay sizes, 3 live loads, 3 wind loads, and 1 building code. The manufacturer would then pull the building from stock and ship it to the site, where it would be quickly erected.

Today, except for small regional manufacturers, the metal building industry has moved to custom engineered designs that are used for a wide range of buildings including non-residential, commercial, industrial, institutional, recreational, agricultural, and so on (see Figure 1 for an example of a complex custom building by RCC). Every design is for what the customer really wants, with the necessary loads, codes and material; there is no "pre-design, pre-detail, or pre-manufacturing." Thus the term "pre-engineered" is somewhat of a misnomer, but it continues to be used to refer to the metal building industry, also to distinguish it from small backyard metal storage sheds.

In the move from pre-engineered standard buildings to custom ones, the challenge before manufacturers such as RCC is to be able to design and manufacture custom buildings, such as the one shown in Figure 1, as fast, as efficiently, and as economically as they do standard buildings. This is where automation comes in.

Figure 1. An example of a complex building manufactured by RCC that was custom-designed rather than pre-engineered. This is the North Raleigh Christian Auditorium in Raleigh, North Carolina. (Courtesy: Robertson Ceco Corporation)

The Decision to Automate

A little over 10 years ago, RCC acquired a new owner who identified two key strategies to become successful and gain a competitive advantage in the industry: command a premium price by delivering faster on higher margin custom-engineered metal buildings than the competition; and lower cost by manufacturing the buildings at significantly lower man-hours per ton, making less mistakes, and increasing the productivity of its designers. After much research and analysis into investigating how these goals could be achieved, the company formulated the strategy of developing a design automation system that would leverage the knowledge of its most experienced designers and that would be tightly integrated into the customer serving process. Some in-house software had already been developed for automating building engineering; however, the building detailing process was still being done manually, and this was the phase where the most time was spent. Detailing was also the phase most impacted by an increase in the size and the complexity of the building, and had a steep learning curve. The focus, therefore, was on looking for a system that would automate design and detailing to the largest possible extent. It was also required that all the work be done in 3D.

After evaluating several object-oriented knowledge-based modeling tools, RCC selected Design Power's Design++ as their automation platform. While it is beyond the scope of the article to describe Design++ in detail, here is a brief overview of how it works in general. Product engineers first define the allowed variations of a product family into a structured "super model" by capturing rules for configuration, design, engineering, and selection of parts in Design++. Design++ then uses these rules to automatically design a product based on its specified functionality. It selects standard parts and engineers non-standard parts, and then lays them out in space to create a custom configuration for the product. Design++ links to standard CAD applications such as AutoCAD and MicroStation for visualizing the product in 3D. It also uses CAD to automatically create drawings complete with properly placed sections, details, dimensions and annotations.

Let us now look at how specifically RCC has utilized this solution.

How RCC Is Using Design++

RCC first captured its metal building engineering/design knowledge in the form of rules into the Design++ system. Based on this super model of metal buildings, two separate systems were then developed: an Engineering Design System (EDS) and an Expert Detailing System (XDS). This key to the success of the knowledge capture task was that it was performed by experienced metal building experts as opposed to software engineers, and they continue to evolve the automation systems as RCC's building scope expands. Design++ automatically derives, to a large extent, the engineering and design process that are related to the knowledge capture, i.e., when to perform the various tasks, what tools to use, and what situation dependent knowledge to use for the various tasks. The remaining process knowledge has to be explicitly input in the system.

This is how the system is applied to a project: RCC receives the desired envelope specifications for the building from the future building owner or the owner's architect. These specifications, along with any other relevant information such as applicable building codes, etc., are fed into the EDS, which automatically performs the building engineering and produces the input for the XDS. The XDS then engineers and details each component of the metal building (its primary and secondary structure and cladding) and produces a complete detailed 3D model and an underlying building information model (BIM) of the building (see Figure 2). These models are first reviewed by RCC's engineers and detailers for completeness, and then by the owner or architect. Any requests for design changes that come in, such as moving a door or window, extending a bay, and so on, are input into the EDS and the XDS systems, and the models are automatically updated to reflect the changes.

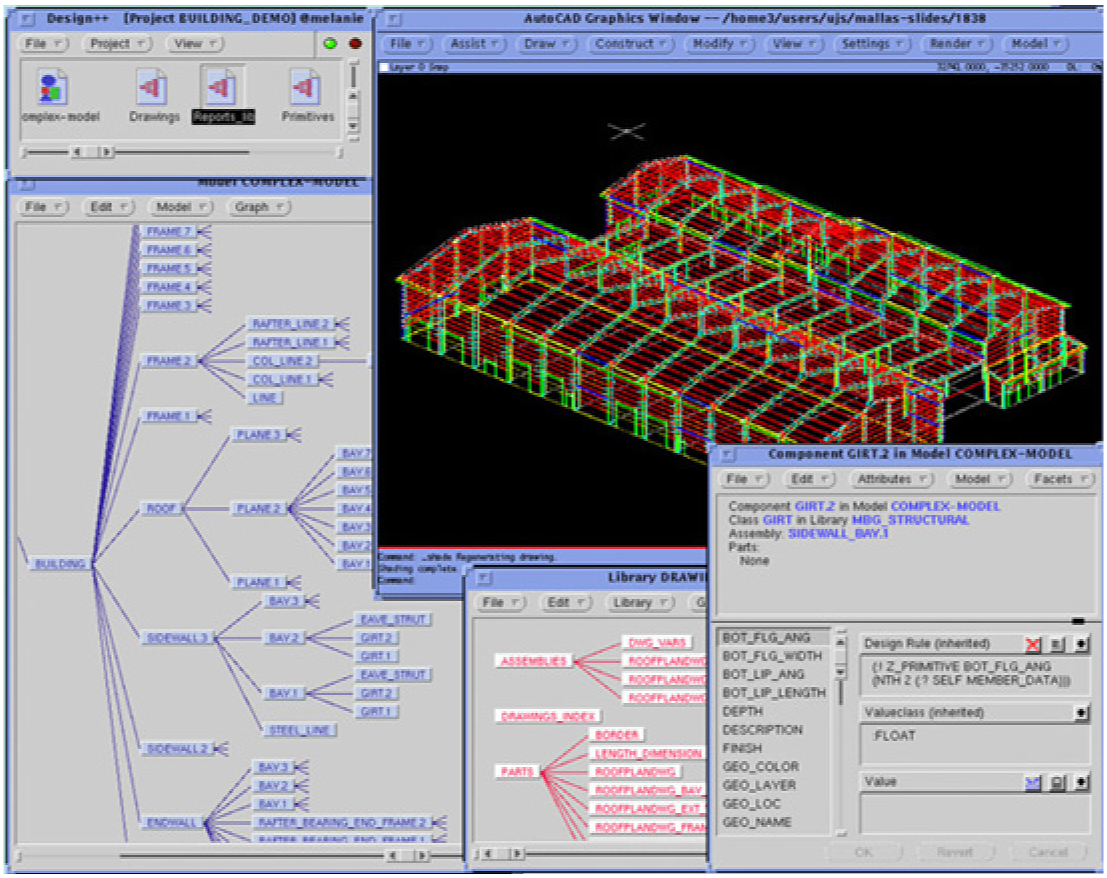

Figure 2. A screenshot of the Design++ interface, showing parts of RCC's knowledge capture of metal building design, the core super model, and the 3D model of a specific building that was automatically generated by the system. (Courtesy: Design Power Inc.)

The automated design and drafting produced by the XDS is 90-98% complete, depending upon the amount of unique features in the building. The automated engineering done with the EDS, which is still being extended, is close to 98% complete for the simplest buildings and 50-60% complete for the most complex buildings. The tasks that are remaining are not automated, as they are either highly custom, or occur so seldom that the added knowledge capture for these few occurrences does not justify the automation cost. In addition, the EDS is still being enhanced with continuing knowledge capture, as mentioned earlier. Once the design is accepted, the system produces a complete set of design calculations, the entire set of shop and erection drawings that usually range from 50 to 200, a complete set of Bill of Materials for multiple vendors, and the data that is need for manufacturing to automatically create both custom and standard parts along with the shipping and delivery documentation.

Let's look at the concept of rules in a little more detail, which are the basis of knowledge capture in Design++. There are around 15,000 unique rules in the RCC system, some simple, some complex. Rules can be used to determine the values of attributes, define configurations, maintain relationships, and so on. Two examples of rules and their results are shown in Figure 3. The first example shows the rule used by a purlin-a lightweight roof beam-to calculate its weight (Figure 3-a), and the use of this rule by a specific purlin in the model to determine its weight, which is 10.935 as calculated by the rule (Figure 3-b). The second example shows the rule used by the roof manager to create roof surfaces in response to walls that link to it via a "need-roof" relation (Figure 3-c). The application of this rule results in the creation of two roof surfaces as shown (Figure 3-d). Some other aspects can be noted from these illustrations. For instance, Figure 3-d shows the top level of the building model with 11 components. A building model in RCC's case can have up to 200,000 of these components.

Components are defined in libraries, and comprise of attributes that define them, as shown in Figure 3-b. In RCC's case, there are at an average about 50 attributes per component. The values of most attributes are determined by rules. The attributes include information on their functionality, and also contain dynamically created and maintained relations, or "dependencies" as they are called, to other attributes. These dependencies are key to the "Intelligent Change Manager" (ICM) in Design++, which propagates any change to a fully populated model as far as needed.

At the leaf level of the building model (which would be the opposite end of the illustration shown in Figure 3-d), there are physical components such as clips, girts, purlins, etc. that have geometric representations. These components communicate bi-directionally with a CAD application-which in RCC's case is AutoCAD-to render the geometries. Higher up in the hierarchy are "assemblies" that typically have no geometric representation, but which distribute and consolidate information and act as "configurators" that determine what type of objects to create and how many. The roof manager shown in Figures 3-c and 3-d is one such type of configurator.

In a typical RCC project, only a few top level components are always present, and these constitute a "seed model." Some of these top level components act as user/interface "brokers" and automatically expand the entire model to include all the lower level components once the building definition is provided. As mentioned earlier, an RCC model can expand up to 200,000 components. The expansion is carefully controlled by a recursive "Execution Order Controller," which resolves in what order to apply the rules and create the dependencies. When the expansion is complete, the fully populated model with all its attribute values constitutes a detailed Building Information Model. This ability to generate a complete BIM from a limited set of user inputs has led Design Power to coin the term "Super BIM" for the collection of libraries of intelligent components, the seed model, and the Design++ engine.

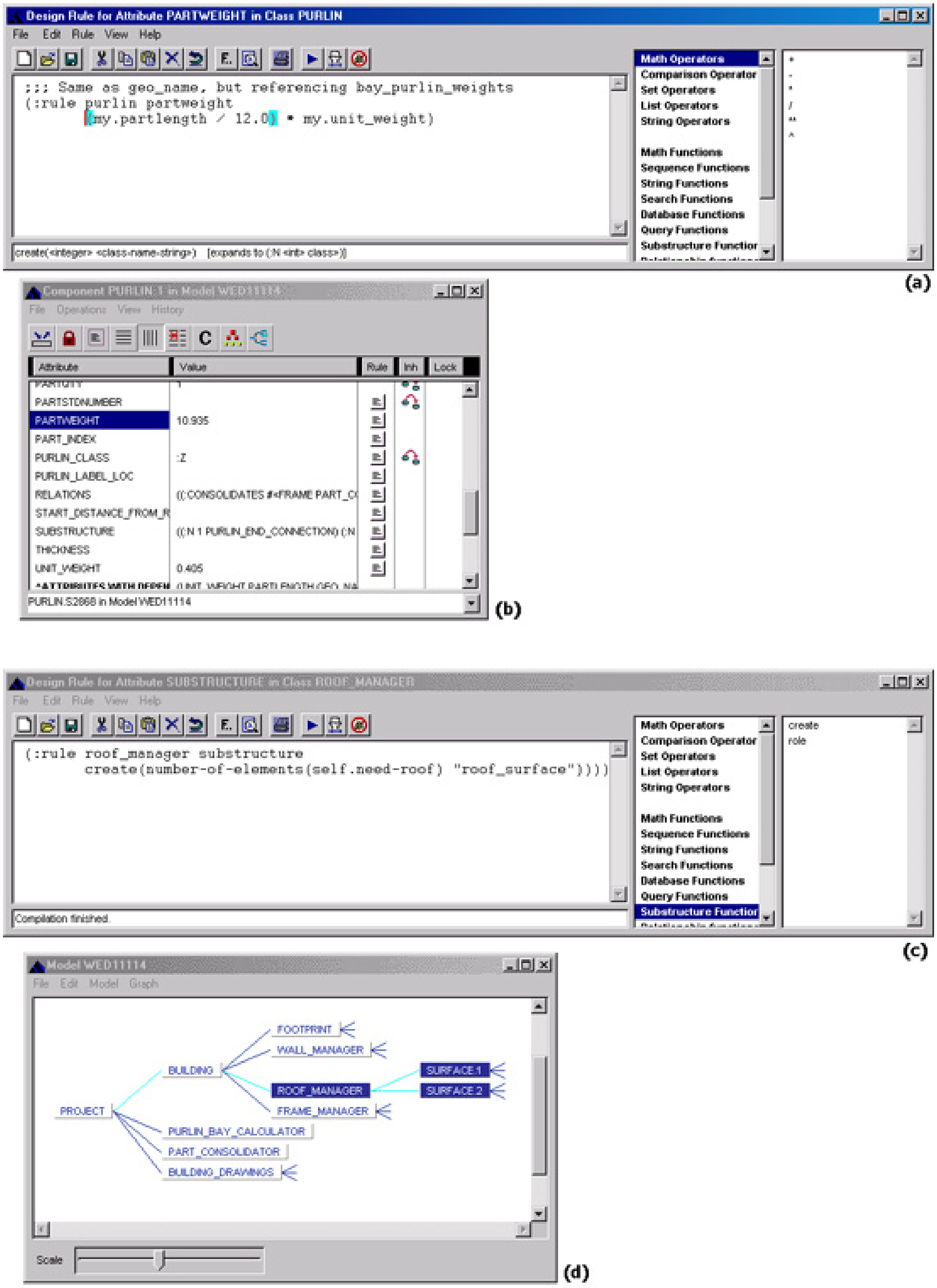

Figure 3. Two examples of rules and their results in RCC's Design++ system. (Courtesy: Design Power Inc.)

The Impact of Using Automation

Today, RCC engineers and designs approximately 7,000 unique buildings a year using their Design++ enabled EDS and XDS systems (see Figure 4 for two more examples). Its design and engineering tasks automated with these systems now take a fraction of the time that it used to earlier. In addition to increased efficiency and accelerated delivery time, RCC is also seeing improved building quality and the ability to tackle designs of greater complexity. The latter is particularly critical since the complexity of buildings that companies like RCC are commissioned to manufacture continues to rise.

For RCC, much of the ROI (return on investment) of developing and maintaining its Design++ systems has been actually measurable in many ways: a 40 to 60% reduction in design time has led to a record rise in productivity; the charge back due to errors has dropped to a third of what it used to be; before going private in 2001, RCC's profitability hovered around 8% while the industry average was below 4%; the design staff has only grown 10% even though the volume of work has grown more than 50% and the complexity has grown approximately 40%. While its competitors have been forced to outsource work to lower-cost countries to stay competitive, RCC has achieved record market share and profitability. It has grown from a $250 million company in 1994 to a $400 million+ company today, in contrast to the overall growth of the metal building industry that has been slightly negative.

Conclusions

By automating its design and engineering process with the use of advanced, cutting-edge technology, RCC has successfully met the ultimate challenge of a pre-engineered metal building company that was mentioned in the beginning: being able to design and manufacture custom buildings as fast, as efficiently, and as economically as standard buildings. Automation was the key for RCC to gain and maintain a competitive edge in the metal building industry.

In terms of the technology itself, the next step for applications such as Design++ would be to communicate bidirectionally with BIM applications such as Revit Building and Revit Structure, ArchiCAD, and the Bentley Building suite, instead of just the CAD applications to which it now connects. This would allow better model-based integration between specialized work on a building, such as the design and engineering of the metal frame by a company like RCC, with the traditional architectural, engineering, and construction work on a building. It would also allow rule-based automated design to be explored for other aspects of architecture and engineering.

Rule-based design may seem like a novel and rather esoteric concept, but the idea of using computation for automatic generation of design has been around in the research community for a long time. Referred to as "generative systems," these have been developed by researchers for different aspects of design such as space layouts, material selection, façade treatments, and so on. They work by capturing the rules for the design aspect in question, which are then used to generate alternatives for an actual design based on specified criteria. I developed such a prototypical system myself several years ago for my M.Phil. thesis project at the University of Cambridge in the UK-given the required daylighting levels in a room, the system would generate all possible window configurations which satisfied those criteria, from which the desired configuration could then be selected. It is a different approach to design-somewhat like reverse engineering. The idea is not to let computers take over the design completely, but to assist with generating aspects of it that are well-defined and can be algorithmically calculated.

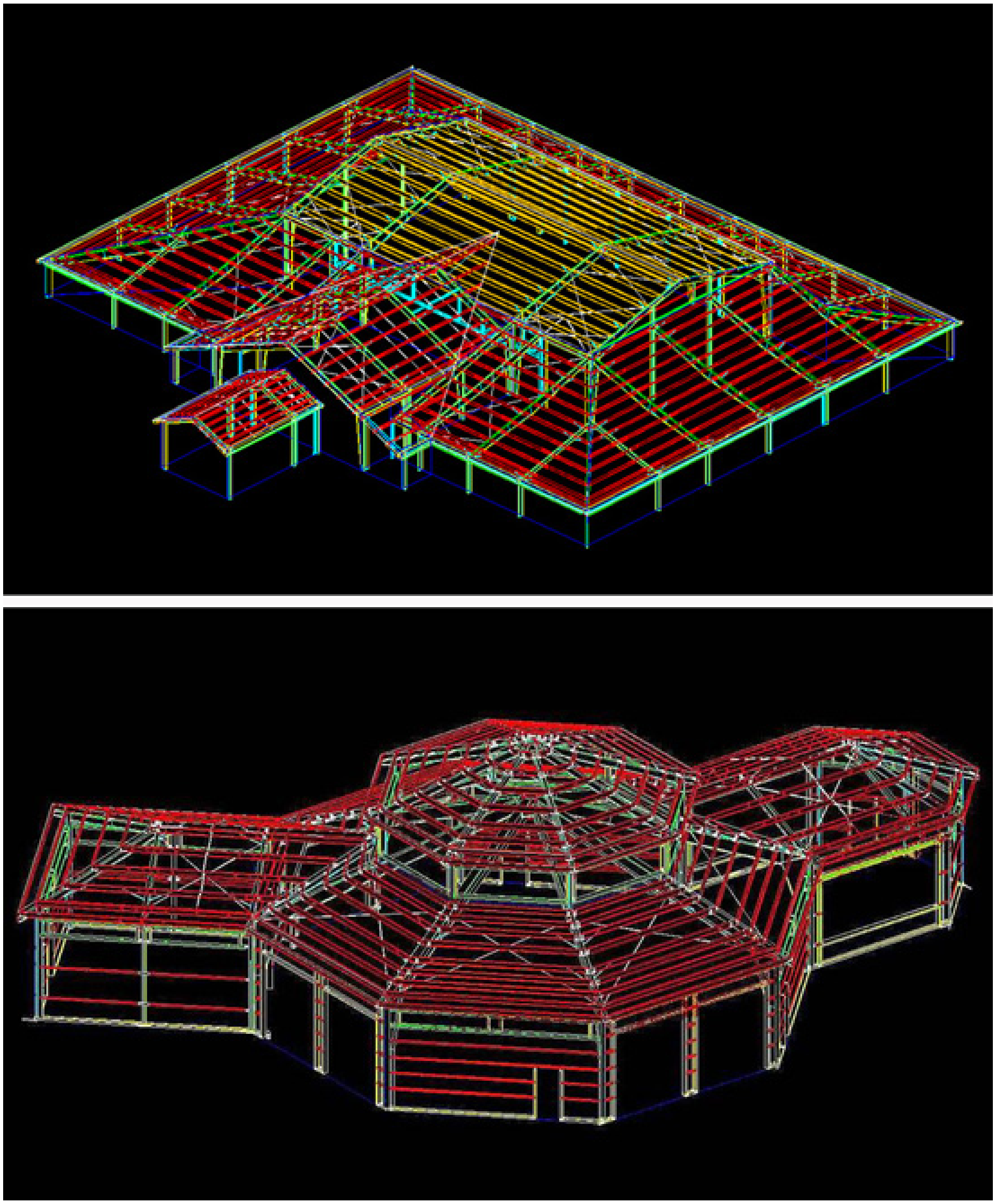

Figure 4 .Two more examples of building designs automatically generated by RCC's Design++ based systems. (Courtesy: Robertson Ceco Corporation)

It is heartening to see some ideas that have been under research for so long finally make it to actual implementation in professional practice in the AEC industry. The most critical aspect of BIM is that it provides an intelligent platform on which many more sophisticated applications can be built, rule-based systems being one of them. RCC's use of Design Power's "Super BIM" is a good example of the exciting possibilities ahead.

Acknowledgments

This article could not have been written without the help of Robert Carr, Vice President of Technical Services at Robertson Ceco Corporation, who took the time to talk to me at length about the pre-engineered metal building industry and RCC's use of Design++, and supplied some of the illustrations for this article. Many thanks also to Ulf Strom, President and CEO of Design Power, and Dr. Craig Howard, Ph.D., Vice President of Applications at Design Power, for explaining to me how Design++ works and supplying me with a lot of material for this study.

About the Author

Lachmi Khemlani is founder and editor of AECbytes. She has a Ph.D. in Architecture from UC Berkeley, specializing in intelligent building modeling, and consults and writes on AEC technology. She can be reached at lachmi@aecbytes.com.