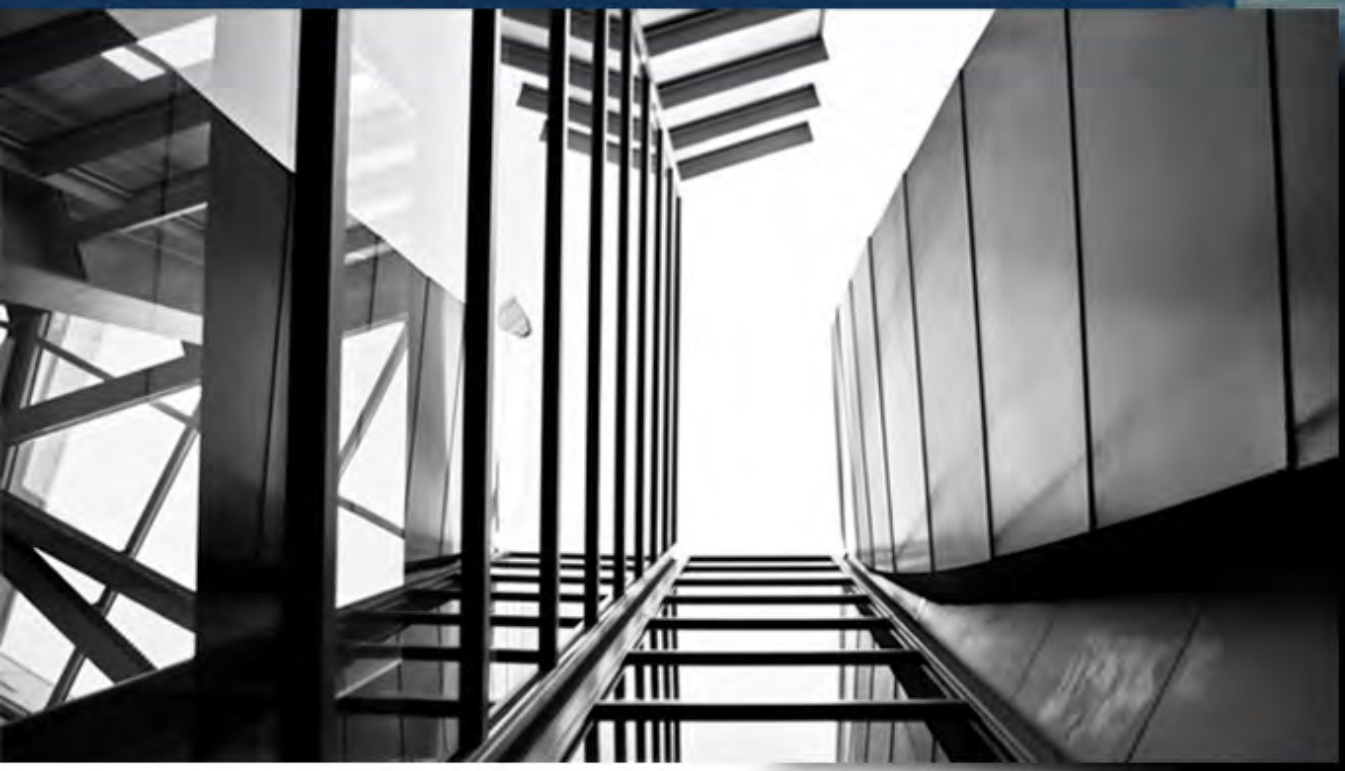
BIM EVALUATION STUDY REPORT

For the AIA Large Firm Round Table (LFRT) CEO Committee



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Executive Summary

It has been close to seven years since Building Information Modeling (BIM) started gaining momentum in the AEC industry. With BIM, a building is designed and represented using digital 3D models instead of the traditional 2D drawings that were being created during the long CAD era that preceded BIM. The move from CAD to BIM has been even more dramatic and revolutionary than the move from hand-drafting to CAD in the pre-computer days; although CAD had replaced paper as the medium, AEC professionals were still, by and large, creating 2D representations of designs such as plans, elevations, and sections. In contrast, with BIM, the focus is on creating a digital prototype of the building design that captures the attributes of the different building elements and their relationships; the drawings are then simply derived from the building model, almost as a byproduct. Eventually, a time will come, perhaps sooner rather than later, when the 2D drawings are not required at all and the building can be constructed from its digital model alone. Thus, BIM represents a disruptive technology in the AEC industry. Not only does it change how the individual building disciplines do their own work, it also changes how they come together to collaborate and coordinate their respective parts of the design. It is hardly surprising then, to find that alternate building delivery models such as IPD (integrated project delivery) are also gaining in momentum along with the BIM technology that facilitates them.

Apart from the underlying technology, one of the significant differences between BIM and CAD is the business climate surrounding them. The CAD era in the AEC industry was dominated primarily by one product, AutoCAD, and by its developer, Autodesk. With BIM, however, the competitive landscape is not as stark. While Autodesk still dominates with Revit—the BIM application it acquired in 2002—AEC firms and, in particular, architectural firms, have many more options to choose from. These include applications such as ArchiCAD and Allplan, which had BIM-like capabilities well before Revit was even developed; the Bentley suite of BIM solutions built on top of its flagship CAD application, MicroStation, which are considered as robust and reliable; Digital Project, which was developed based on the high-end mechanical CAD application, CATIA, by a spin-off company from Frank Gehry's firm and has highly sophisticated form-making and parametric modeling capabilities; and Vectorworks Architect, which is not yet as sophisticated or comprehensive as the other BIM applications, but is extremely cost-effective.

Given this fairly large array of options for BIM applications, the challenge before architectural firms is to decide which one to adopt, or if they have already implemented BIM, to either validate their choice or determine if another application would better serve their needs. The AIA LFRT (Large Firm Round Table), which is a group of the largest architectural firms in the US, falls in the latter category. Their CEO Committee decided to commission an independent third-party study of the different architectural BIM applications that would provide them with a better understanding of the strengths and limitations of each application, which, in turn, could help to guide their technology implementation decisions. The results of this BIM evaluation study are captured in this report. The bulk of the evaluation is focused on studying the technical capabilities of each application in detail, accomplished by installing and working with the latest version of the software. In addition, the study also looks at implementation aspects including pricing, training, technical support, and the current market position of the applications, as well as the long-term potential of their vendors. This information was compiled through market research, information gathered from the vendors themselves, and from talking with a diverse range of firms implementing each of the applications. Also, while the study was commissioned by the AIA LFRT CEO Committee, the CIOs of the LFRT firms were kept updated on the progress and results of the study and were encouraged to provide suggestions and feedback, which have been incorporated in the report.

The results of this study indicate that there is no "best" solution that has emerged superior to all the others. While Revit is the most modern and definitely has the edge when it comes to intuitiveness and ease of use, ArchiCAD leads in having the best collaboration solution. It also has less performance issues than Revit when it comes to modeling large projects, thanks to a more efficient file structure. However, both of these being centralized BIM applications where the building model is primarily stored in one file, they eventually run into performance issues as the model size increases, with this happening sooner for Revit than for ArchiCAD. Users then have to rely on strategies such as breaking up the model into parts that are linked together to form the complete project.

Bentley and Allplan, while being comprehensive multi-disciplinary BIM solutions that can be implemented on large projects without any significant performance issues, suffer from the complexity and limited object associativity that come with a distributed approach to BIM. Their project setup is much more involved and requires careful planning before getting started on creating a building model. Also, because the model is distributed across multiple files, it does not behave as a consolidated whole—changes made to the model in one file do not automatically "ripple through" and modify the associated elements in other files.

Digital Project, in contrast, also uses a distributed file approach but has engineered it so that the different parts of the model distributed across multiple files still behave as a consolidated whole. It has also developed a smart display technology that allows even very large models to be easily opened, viewed, and edited without any significant slow-down in performance. Thus, it solves the problem of object associativity in distributed solutions such as Bentley and Allplan as well as the performance issues in centralized applications such as Revit and ArchiCAD. Also, it has parametric capabilities that are far superior to any of the other BIM applications, including Revit. However, Digital Project is a very complex application with a very different approach to design and BIM, making it best suited only to highly specialized projects and highly sophisticated users.

As far as Vectorworks Architect is concerned, it handily beats all the other solutions from a cost perspective, but it is still building out its BIM capabilities and does not yet provide all the tools and features that the other BIM applications have to offer.

In addition to the intrinsic capabilities of each application, it is also important to consider other aspects such as the vendor and the "ecosystem" surrounding each tool. As far as the vendor is concerned, the firm case studies clearly show that Graphisoft, developer of ArchiCAD, gets the highest marks for responsiveness and support. In contrast, market leader Autodesk receives some flak for not being very communicative or responsive to feature requests and support calls, although the company seems to have improved upon this of late. When it comes to third-party tools and content development, Revit is the hands-down winner—the universe of Revit content, third-party tools, training content, blogs, and so on is constantly growing, thanks to its position as market leader. Thus, despite Autodesk's lower rating for responsiveness compared to the other vendors, working with Revit is made much easier through the support of the large community of users and developers surrounding it.

So how should firms go about deciding which BIM application to implement, since there's no one "best" solution that ranks significantly higher than all its competitors? The most logical way would be for firms to first determine the criteria that are most important to them, and then look at how the different applications are rated for those criteria in this study. This would enable them to identify the solutions that work best for the issues most important to them. This ranking of criteria—including not only their order of importance but also a weightage to determine how important they are relative to other criteria—would be unique for every firm, which is why there is no single universally best solution for all firms. It is also possible that even within a firm, there is no one best solution that emerges for all of its diverse projects, clients, and employees, in which case, the firm can make a conscious

decision to implement more than one BIM application, as some of the firms that participated in the implementation studies have already done.

Developing expertise in more than one BIM application might, in fact, be prudent for all the AIA LFRT firms, given their size and the large and diverse number of projects they handle. Since all of the individual BIM applications that were evaluated have their individual strengths and limitations, with no solution emerging as decidedly superior to the others, implementing more than one solution allows a firm to enjoy the "best of many worlds"—the different strengths and continuing innovations in the different solutions. It also gives the firm the added benefit of not being locked down to one solution and one vendor, greatly increasing the firm's leverage with all of its vendors.

While this study has been focused on BIM, and more specifically, on architectural BIM, it should be emphasized that BIM is not the panacea for all of the problems facing the AEC industry. Multi-disciplinary collaboration still remains a significant challenge, and BIM applications for the other building disciplines, especially MEP engineering, are still far from mature. Interoperability between the different disciplinary BIM applications, as well as between BIM applications and downstream tools for tasks such as analysis, is far from seamless. The IFC file format, developed as the main solution for interoperability in the AEC industry, does not work flawlessly and firms have to devise various workarounds to be able to use it, if they use it at all. Distributed project teams continue to struggle to work together on the same project, and while ArchiCAD has demonstrated a significant step forward on this front with its new server-based collaboration capability, it will take a while before other solutions like Revit can catch up.

Also, BIM itself is just the tip of the iceberg when it comes to AEC technology. Compared to other fields such as EDA (electronic design automation, or CAD for the computer chip industry) where the lower level design tasks have almost entirely been automated, BIM is still a relatively "dumb" technology where the user is forced to model everything in the building. Our vendors need to be pushed into developing smarter rule-based BIM applications where the lower-level design details are automatically designed by the system, leaving the designer to focus on the higher-level design aspects of the building. While BIM is a terrific start towards improving the technological state of the art of the building industry, a lot more remains to be done ahead.

About This Report

This report captures the results of the BIM evaluation study that was commissioned by the AIA Large Firm Round Table (LFRT) CEO Committee to provide an in-depth comparative evaluation of all the main architectural BIM applications that are currently available. The bulk of the evaluation is focused on studying the technical capabilities of each application in detail, accomplished by installing and working with the latest version of the software that was available at the time of the evaluation. In addition, the study also looks at implementation aspects including pricing, training, technical support, and current market position of the applications, as well as the long-term potential of their vendors. This information was compiled through market research, information gathered from the vendors themselves, and from talking with various firms implementing each of the applications.

The six applications included in the study are listed below. The version of the application that was evaluated is also indicated.

- Revit Architecture 2010 from Autodesk
- Bentley Architecture V8i
- ArchiCAD 13 from Graphisoft
- Allplan Architecture 2009 from Nemetschek AG
- Vectorworks Architect 2010 from Nemetschek North America
- Digital Project V1, R4 from Gehry Technologies

For each of these applications, a detailed report is presented on the following pages, which includes:

- *Overview* of the application and its vendor.
- *Evaluation summary* highlighting the main strengths and limitations of the application, along with its list price.
- Detailed evaluation tables looking at criteria organized into six categories as shown below:
    - *Application repertoire*: The range of tasks that can be performed with the application.
    - *Intrinsic nature and capabilities*: Different aspects of the application that play an important role in determining how well it performs.
    - *Issues specific to large firms*: Aspects specific to large projects and distributed teams and workflows.
    - *Interoperability*: Exploration of well the application works with other tools, both from within the architectural discipline as well as from a multi-disciplinary perspective.
    - *Implementation*: Aspects related to the deployment of the application at a firm.
    - *Vendor*: Evaluation of the vendor's responsiveness and long-term potential.
- Extended discussion of some of the key features of the application, including:
    - *Project setup*
    - *Interface*
    - *Functionality*
- *Conclusion* summarizing the key points about the application and its future outlook.

After the detailed evaluation report of each application, a comparative evaluation chart of all the six applications is shown. This allows a quick side-by-side comparison of all the applications for each of the criteria listed in the evaluation tables.

This is followed by implementation studies of the six applications at various firms to explore how successfully each of them has been deployed, the challenges involved, training processes, and the overall level of satisfaction with the application. This section also includes the results of a brief survey conducted among the LRFT firms to determine which BIM applications they are actively using as well as the ones that are being explored for possible implementation in the future.

The report concludes with an overall analysis of the findings of the study, the suggested recommendations for BIM implementation that emerge from it, and a brief discussion of the future outlook of BIM and AEC technology.

Revit Architecture

Prior to Revit, the term BIM did not exist in the AEC industry. Even though there were applications like ArchiCAD, Allplan, VectorWorks Architect, and Bentley Architecture (known then as Architecture for MicroStation TriForma), these applications were simply referred to as CAD applications, or sometimes, architectural CAD or object-oriented CAD applications in order to differentiate them from general-purpose, drawing-oriented CAD applications like AutoCAD. Revit burst into the limelight in April 2000 with the first release of its parametric building modeling application and quickly became the upstart in the AEC field, posing what seemed to be a serious threat to the leading vendors, Autodesk and Bentley. However, its run as an independent company ended less than two years later with its acquisition by Autodesk in February 2002. At the time of the acquisition, the fate of Revit was very uncertain. Was Autodesk acquiring the competition just to kill it and ensure the dominance of its own AutoCAD-based architectural CAD application, Autodesk Architectural Desktop (now known as AutoCAD Architecture)? Or would it actively promote Revit's parametric building modeling technology and let the AEC industry finally see an end to the days of "dumb" 2D drawings?

Fortunately, Autodesk took the latter approach, coined the term "Building Information Modeling" or BIM in January 2003 to describe the parametric modeling capabilities of Revit, and continued to develop the application further, expanding it from a single product to a multi-disciplinary platform of BIM applications: Revit Architecture, Revit Structure, and Revit MEP. Since its introduction, BIM has literally taken the AEC industry by storm. After an initial period of hesitation, discussion, debate, and dithering—to be expected in an industry that is notoriously resistant to change—BIM has now been embraced by most of the large AEC firms and many of the medium-sized and smaller ones as well. All the other architectural CAD vendors eventually rebranded their offerings as BIM solutions and strove to implement Revit-like capabilities in them, which has been extremely beneficial for their users as well. Overall, Revit has helped a great deal to push the state of the art of technology in the AEC industry forward. It is important to keep this perspective in mind, and even though Autodesk does come in for a lot of flak for being the 800-pound gorilla in the AEC technology industry, it deserves to be commended for recognizing a good technology, acquiring it, promoting its use, and continuing with its development.

The truism that "nothing breeds success like success" has certainly been true for Revit. The growing use of Revit has led to an ever-expanding number of Revit blogs for users to share tips and learn from, an ever-increasing universe of third-party add-on tools and plug-ins for Revit, and an ever-growing list of content providers creating BIM content to use with Revit. And all of this is happening not just because Autodesk is the market leader—although, of course, that does have a role to play in it—but because Revit is indeed the most intuitive and user-friendly of all the BIM applications currently available. If this were not the case, it would not be as popular in the industry as it is today. Since it was developed from the ground up as a BIM application, it was able to incorporate the latest software development concepts and brought a fresh approach to computer-aided building design—no more Xrefs and layers and the concomitant management hassles. With parametric modeling capabilities that simplify the creation and editing of building entities, intelligent built-in relationships between building components, and a change management capability that immediately synchronizes all graphical and tabular views of a building when a change is made, Revit allows users to concentrate more on design tasks, with the system handling most of the project setup and coordination tasks. It definitely has its deficiencies, of course, and there's much that Autodesk can still do to improve it, the most urgent being better capabilities to model large projects and support distributed project teams. This is one aspect that most of the other BIM applications handle better than Revit, so it's imperative for Autodesk to develop these capabilities in Revit as soon as possible if it wants to maintain its current leading position in the industry.

EVALUATION SUMMARY

Key Strengths

- Newest and most modern, with a fresh approach to BIM
- Easiest to learn, most intuitive to use
- Very quick project setup that allows a user to start modeling right away
- Includes a powerful and sophisticated conceptual design environment with the capability to model parametric freeform shapes and subsequently convert them directly to building elements without starting over
- Parametric objects, built-in relationships between building elements, and the ability to apply additional constraints all enable quick modeling and editing of the model
- Automated change management ensures that all model views, schedules, and sheets are always consistent
- Enables multiple design options for a part of the design to be created in the same file
- Has a worksharing capability with transparent element borrowing to support distributed project teams
- Is part of a tightly integrated multi-disciplinary platform that also includes Revit Structure and Revit MEP
- Supported by a rapidly growing ecosystem of third-party tools, add-ons, and BIM content developers that extend the capabilities of the application in many diverse ways
- Benefits from growing Autodesk acquisitions of key applications such as Navisworks, Ecotect, and Green Building Studio, which are likely to be directly integrated with Revit Architecture in the future
- Developed by the undisputed market leader in the AEC industry and has the most "buzz"

Main Limitations

- Since all the model information (comprising geometry, data, and relationships), views, schedules, and drawing sheets are all contained in one file, model sizes quickly get large and unwieldy and slow down performance
- Collaboration is not real-time or seamless, and has a latency because of the large file sizes
- No concerted attempt to fix file size or collaboration problem until now, despite being aware of it for years
- Lacks a full set of solid and surface modeling tools that are available in some of the other BIM applications
- Model navigation is somewhat clumsy
- Presentations graphics are not as visually rich compared to some of the other BIM applications
- Includes some modeling constraints but allows many illegal operations, providing no guarantee of modeling integrity
- Not fully parametric, despite claims of being so
- API not yet as open compared to other BIM applications
- Lack of video tutorials for general users, which would have greatly speeded up learning
- Annual releases not always focused on solving critical problems: for example, the ribbon-based interface introduced in the 2010 release proved to be very unpopular with users

Price

- Autodesk Revit Architecture is $5,495 USD for a standalone license; AutoCAD Revit Architecture Suite that includes AutoCAD Architecture is $5,995 USD.

DETAILED EVALUATION

Application Repertoire

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Space Planning/ Programming			✓	No built-in tools for programming and space planning; plug-in allows bidirectional integration with Trelligence Affinity, a sophisticated third-party space planning application.
Conceptual Design/ Mass Modeling		✓		New conceptual modeling environment is powerful and sophisticated, with the ability to tie geometry to reference lines and planes, and add constraints and parameters to iterate through multiple design variations easily. However, it still lacks the fluidity and ease of use of a tool like SketchUp.
Detailed Modeling	✓			Has a full suite of tools for created a detailed building model including walls, doors, windows, floor and ceiling slabs, roofs, structural elements including columns, beams, braces, and foundations, curtain systems, stairs, ramps, and railings, as well as tools for site modeling.
Schedules and Reporting	✓			A variety of different types of schedules can be created including counts, quantities, and material take-offs for all building elements, as well as various documentation-related schedules such as drawing lists, view lists, revision lists, and annotation lists. Schedules are just another view of the model, so changes to the model update the schedule automatically and vice versa. Schedules can create totals, include formulas and custom properties, and can be formatted in several ways.
Quantity Take-off	✓			Includes a Material Takeoff tool as part of its scheduling capabilities, which allows quantification of sub-components and materials of building elements such as individual wall layers, finishes, and so on (*see Figure 1*). These can be exported in ODBC format to external database programs for cost analysis and estimating. In addition, there is close integration with the Autodesk Quantity Takeoff application.
Photorealistic Renderings	✓			Includes mental ray rendering engine, extensive library of predefined materials, and photometric lights, which allow high-quality photorealistic renderings to be generated within the application (*see Figure 2*). Special FBX format allows model geometry, lights, and cameras to be exported to 3ds Max for more advanced visualizations.
Animations		✓		Animations can be created using the Walkthrough feature, with the ability to display various levels of detail from wireframe to fully rendered, and can be exported as an AVI file. However, there is no dedicated set of animation tools such as keyframes, timeline and velocity graphs, etc.
Real-time Model Exploration			✓	Includes model navigation tools, but these are not as easy to use as other applications. Also, there is no dedicated mode or environment that allows easy game-like navigation and exploration of the model, similar to what ArchiCAD has.

Construction Documents	✓			Extensive set of dimensioning, annotation, and detailing tools for producing conventional drafting representations, with comprehensive keynoting capability, and automatic coordination of all tags, callouts, and numbering. All documentation stays synchronized with the model at all times.
Coordination/ Clash detection	✓			Includes an interference checking tool to scan the model for collisions between elements within a project or in two linked projects, allowing it to also be used for multi-disciplinary coordination *(see Figure 3).* It also includes a Copy/Monitor tool to help coordinate objects managed by various disciplines, notifying architects and engineers of changes in tracked objects in linked models, so that the designer can update the host model accordingly.
Fabrication			✓	No special capability beyond the ability to export detailed geometry information in ODBC format. No native support for STL or STEP formats commonly used for fabrication.

Intrinsic Nature and Capabilities

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Intuitiveness and Ease of Use	✓			Easiest and most user-friendly of all the BIM applications with quick project setup, heads-up display that allows accurate modeling, tools that work intuitively, intelligent built-in relationships between building components, and a change management capability that keeps all graphical and tabular views automatically synchronized.
Ease of Project Setup	✓			Project setup allows modeling to be started right away, using default or custom template files. Adding a new level to the elevation view automatically creates the corresponding plan views. Project can be contained in a single file, minimizing the need for complex file management. There are a minimal number of constructs to work with (only model views, schedules, and drawing sheets) and no antiquated CAD-like concepts such as layers to manage.
Information Re-Use	✓			Includes a Building Maker tool that allows a conceptual model, created within Revit Architecture or imported from SketchUp, Rhino, form.Z, etc., to be quickly converted to a building model with walls, roofs, floors, and curtain systems. Special scheduling tools are available to work with the massing model and calculate useful information such as floor area and surface area (*see Figure 4*). Moving from design development to detailed design is also simplified by the ability to start with generic building elements and replace them with detailed manufacturer-specific elements at any time.

Modeling of Organic Building Forms		✓		Freeform modeling is only available as part of the conceptual modeling environment described earlier. It allows freeform building masses to be created and converted to building models. However, Revit Architecture lacks a full set of solid and surface modeling tools that are available in some other BIM applications.
Automation of Tasks			✓	Some level of automation is available in parametric content such as stairs and roofs, but there is no built-in automated functionality such as wall framing, column placement on grid points, and so on.
Creation of Parametric Forms		✓		The conceptual design tools introduced in version 2010 allow the creation of parametric massing models, and parametric BIM objects can be created with the Family Editor. But there is no sophisticated parametric modeling capability of the kind provided by Digital Project or Bentley's GenerativeComponents.
Associative Behavior of Building Elements		✓		There is some built-in associativity between building elements, and some custom relationships can be defined, which causes some changes to be automatically propagated to maintain the relationships. But full connectivity is not guaranteed; the model often "breaks" when changes are made.
Guarantee of Model Integrity			✓	While the application has some constraints that dis-allow a number of illegal operations such as overlapping walls, these are not consistent. So, for example, overlapping doors and windows are allowed, even though they are physically impossible in a building.
Availability of BIM Content	✓			Comes with over 4500 items of content contained in libraries referred to as "families," along with a Family Editor to modify these families or create custom ones (*see Figure 5*). In addition, a wide variety of BIM content is available through third-party content developers. Integration of Autodesk Seek within the application makes it easier to pull external BIM content into it.
Customization Capability			✓	Only the Project Browser can be customized. The rest of the interface cannot be customized at all. Users are stuck with the new ribbon-based interface that has proved to be unpopular.
Support for 3D Printing		✓		Revit does not provide this capability natively. However, an STL Exporter plug-in that is available (on Autodesk Labs) can be used to export Revit models to 3D printers.
Multi-Processing Support		✓		Only some tasks such as rendering, printing, and wall-join cleanups currently take advantage of the multiple cores on a computer.
64-bit OS Support	✓			Revit now has native 64-bit support, which enhances its ability to handle large projects and improves performance and stability for memory-intensive tasks such as rendering, printing, model upgrading, and file importing and exporting.
Cross-Platform (Windows, Mac)			✓	Revit is a Windows-only application.

Issues Specific to Large Firms

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Model Performance			✓	Revit files contain not only object geometry and attributes but also relationships and constraints, and all project information is contained in one file, so they tend to get very large (between 100 to 450 MB) and increasingly demanding on system resources as the project gets more complex. A model can be divided into worksets to segregate different parts of a project and make it easier to work with.
Model Sharing Technology		✓		There is a Worksharing feature that allows multiple team members to work on a project, along with a transparent element borrowing capability that automatically assigns ownership of an edited element to a user. Users can "borrow" elements that are being edited by other users. However, there is no built-in instant messaging capability to communicate such borrowing requests, and no way to see who is working on what part of the model. Changes made by others can be seen only when they "check in" their copies of the model. So collaboration is not real-time and fluid.
Support for Distributed Workflow		✓		Includes a Worksharing Monitor that provides useful real-time information to team members such as the current status of central files. They can monitor progress of editing requests and notifications and plan for the best time to save their local copies to the central model.
Security and Access Controls	✓			When worksets are used, they are individually locked to a single user, providing a degree of access control to areas of the model. Only users who have network access to the storage area of the model, and the matching Revit-based product version and discipline of the software, can work on it.
Performance Across WAN			✓	The large file sizes lead to performance issues when a model is shared in a WAN environment. If worksets are used, they can be synchronized with the central file faster.
Ability to Handle Large Projects		✓		Large projects can be broken down into smaller models that can be linked together into a master model. But this is typically done for projects comprising of multiple buildings such as a campus. The 64-bit version has better capability to handle large projects, but the huge file sizes still make large projects a challenge in Revit.

Interoperability

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Integration with Structural BIM Applications	✓			Includes direct integration with Revit Structure. Integrates with other structural applications through IFC.
Integration with MEP BIM Applications	✓			Includes direct integration with Revit MEP. Integrates with other MEP applications through IFC.
Integration with Sustainable Design Tools		✓		There is no direct integration with Ecotect or Green Building Studio, except through gbXML export, even though these are now Autodesk's applications.
Integration with Estimating Applications	✓			Direct integration with Innovaya's suite of tools enables a Revit model to be used to produce a detailed cost estimate using Sage Timberline's established cost estimating engine.
Integration with Constructability Tools		✓		Revit Architecture includes construction-specific parametric components such as scaffolding, cranes, and trailers and the ability to model and analyze construction logistics and staging scenarios within the application. In addition, there is integration with Vico's Virtual Construction Suite, and Synchro, a 4D construction management and simulation application.
Electronic Publishing and Review		✓		Publishes 2D and 3D DWF files and supports round-tripping of markups with Autodesk Design Review software (*see Figure 6*). However, it does not export 3D PDF files.
Range and Quality of Third-Party Tools	✓			Revit Architecture has the largest number of third-party add-on tools available of all the BIM applications, many of which have already been mentioned here. Others include eSpecs and BSD SpecLink for automated specifications from the model, Nova for model visualization, and ArchiBUS for facilities management. A full list of add-ons can be seen at: http://partnerproducts.autodesk.com/compatiblewith/revit1.asp.
Number of 3D File Formats Natively Supported		✓		Supports only a limited number of 3D file formats compared to other BIM applications. These include DWG, DXF, DGN, IFC, and ACIS SAT. It can also import SketchUp files.
Quality of API (Application Programming Interface)		✓		The API is still not as extensive as the other BIM applications but is being enhanced in every release. It has been adopted by many third-party vendors to create add-ons or integrate their tools with Revit. In addition, a VSTA (Visual Studio Tools for Applications) plug-in is available to create macros for smaller tasks such as changing the case of text, finding and replacing text, finding and replacing window types, etc.
IFC Support	✓			Revit Architecture supports the latest version of the IFC file format.

Implementation

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Initial and Ongoing Pricing/Licensing		✓		Pricing is competitive with comparable BIM applications such as ArchiCAD and Bentley Architecture. Pricing depends on whether a license is new, an upgrade, or eligible for cross-grade from another Autodesk product. Autodesk sells many of its products through independent distributors, and prices may vary from one dealer to another depending on the added value a particular dealer delivers in conjunction with the product sale. There are additional subscription options as well as licensing options for large firms. Autodesk has forced upgrade policies that are very unpopular.
Initial and Ongoing Training		✓		There is no free training apart from the documentation and online learning resources. But paid training is available from Autodesk as well as from its large network of resellers and consultants.
Quality of Technical Support		✓		Autodesk provides installation support for free and technical support for subscription customers for a fee. The fee-based support is available at different levels and can include web/email support, phone support, as well as dedicated service account managers depending on the support plan purchased. There is also a pay-per-incident support option. Free support is available via an online knowledge base, various blogs, and discussion forums.
Quality of Included Documentation		✓		The quality of the documentation has been improved in recent years, but there is still a lack of video tutorials for general users that would greatly help to speed up learning.
Free Online Learning Resources	✓			A tutorial that provides a good overview of the application can be downloaded, along with the Revit files for each step, which is extremely helpful. There are also several additional learning resources posted on the Revit website, many of them in several languages in addition to English. In addition, there are a multitude of blogs and websites with how-to articles and tips, which can be very helpful to new users.
Support Channel (Resellers and Consultants)	✓			Revit is supported by a vast network of distributors, resellers, and consultants all over the world. The application has a truly global presence and reach.
Availability of Trained Staff	✓			Revit's power and ease of use, combined with Autodesk's leading position in the AEC industry, has made Revit the most ubiquitous BIM application. It is also the leading BIM application used by students at schools. This makes it much easier to find staff knowledgeable in Revit compared to other BIM applications.

Vendor

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Current Market Position	✓			Revit Architecture is currently the leading BIM application used for architecture in the US as well as world-wide.
Long-term Viability	✓			With Autodesk being the industry leader by far in the AEC industry, the long term viability of Revit is all but guaranteed.
Investment in R&D		✓		Despite being the market leader, the lack of radical innovation in Revit in the last few releases indicates insufficient investment in R&D for it.
Responsiveness to Feedback and Requests		✓		The Revit team formally gathers customer feedback in a variety of ways including focus groups, surveys, customer councils, customer interviews and visits, through AUGI, major account questionnaires, alpha and beta programs, and voluntary automated feedback from applications. There are also many blogs and discussion forums by Revit team members where users can post feedback and make product requests. However, recent releases have not addressed critical problems, indicating that features are not always developed in response to requests.

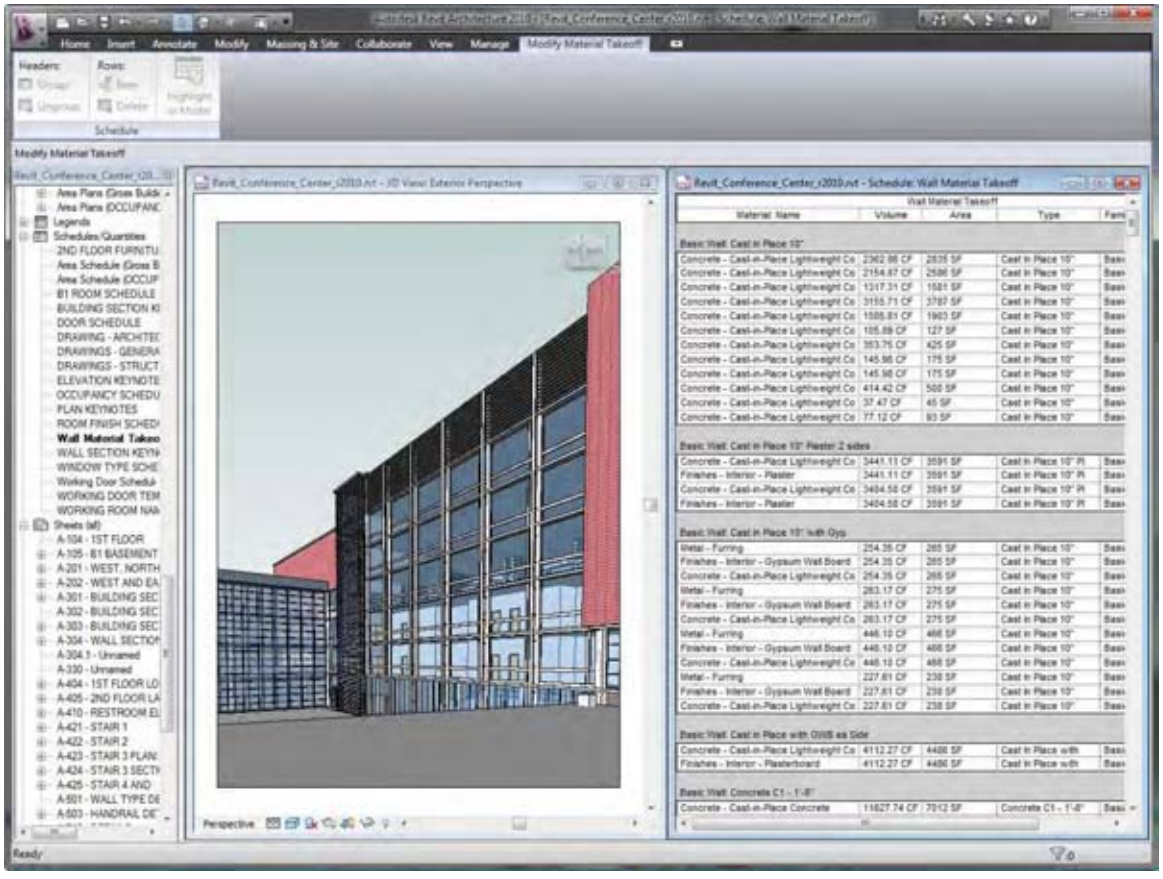


FIGURE 1. A wall material takeoff schedule for a project in Revit Architecture.

FIGURE 2. Examples of renderings generated directly in Revit Architecture.

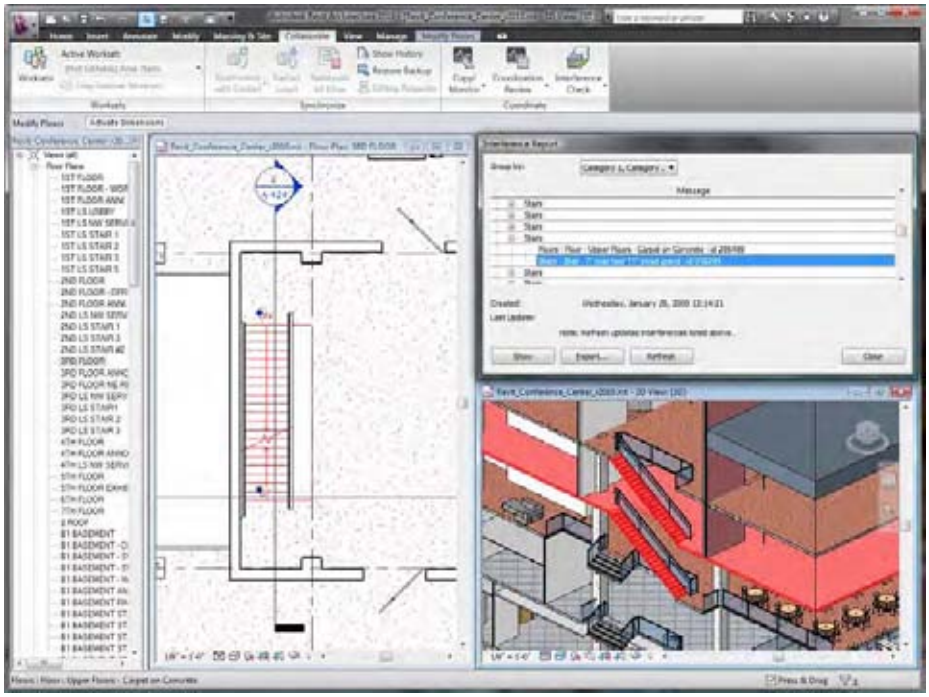


FIGURE 3. Using the Interference Check tool to detect a clash in the model.

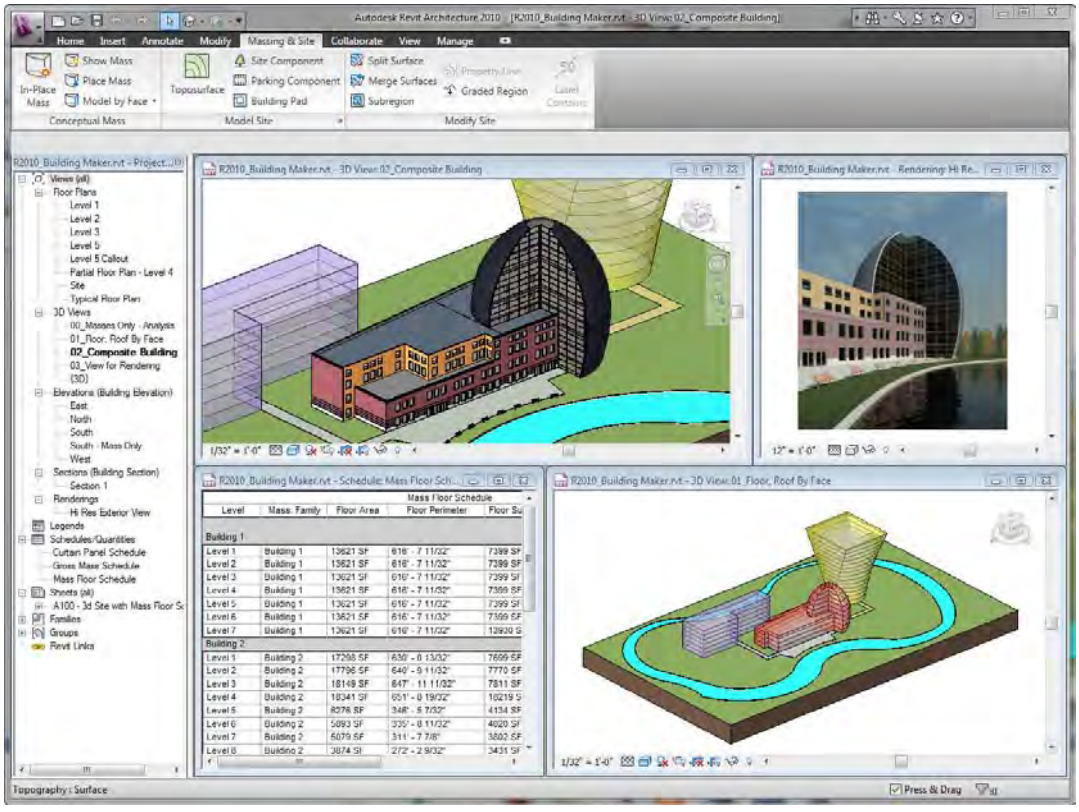


FIGURE 4. Using the BuildingMaker functionality to convert a massing model to a building model, with calculation of the floor areas in the massing model.

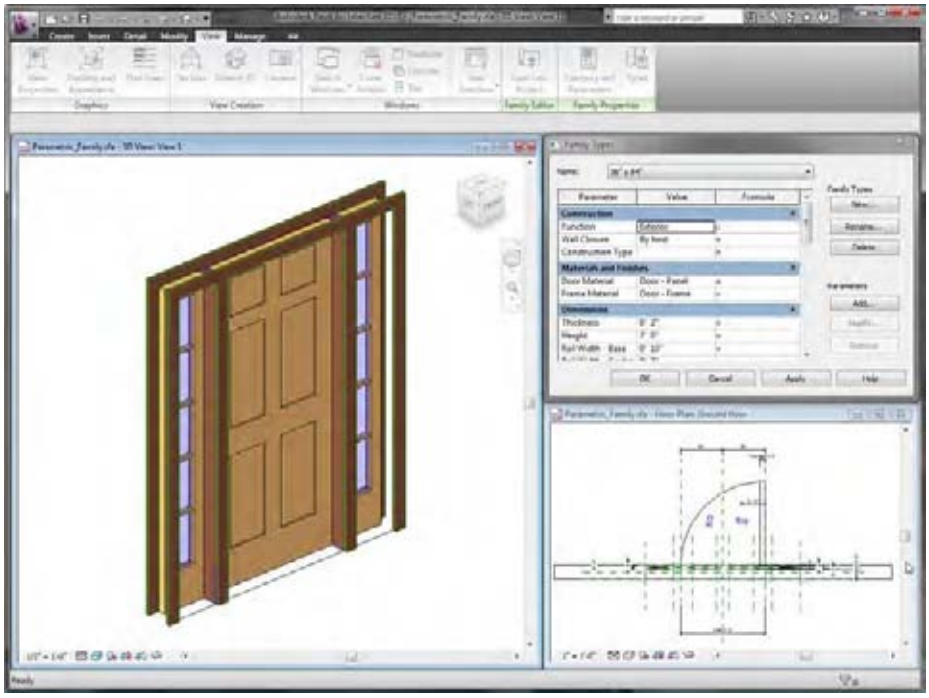


FIGURE 5. Modifying the parameters of a parametric door family in the Family Editor.

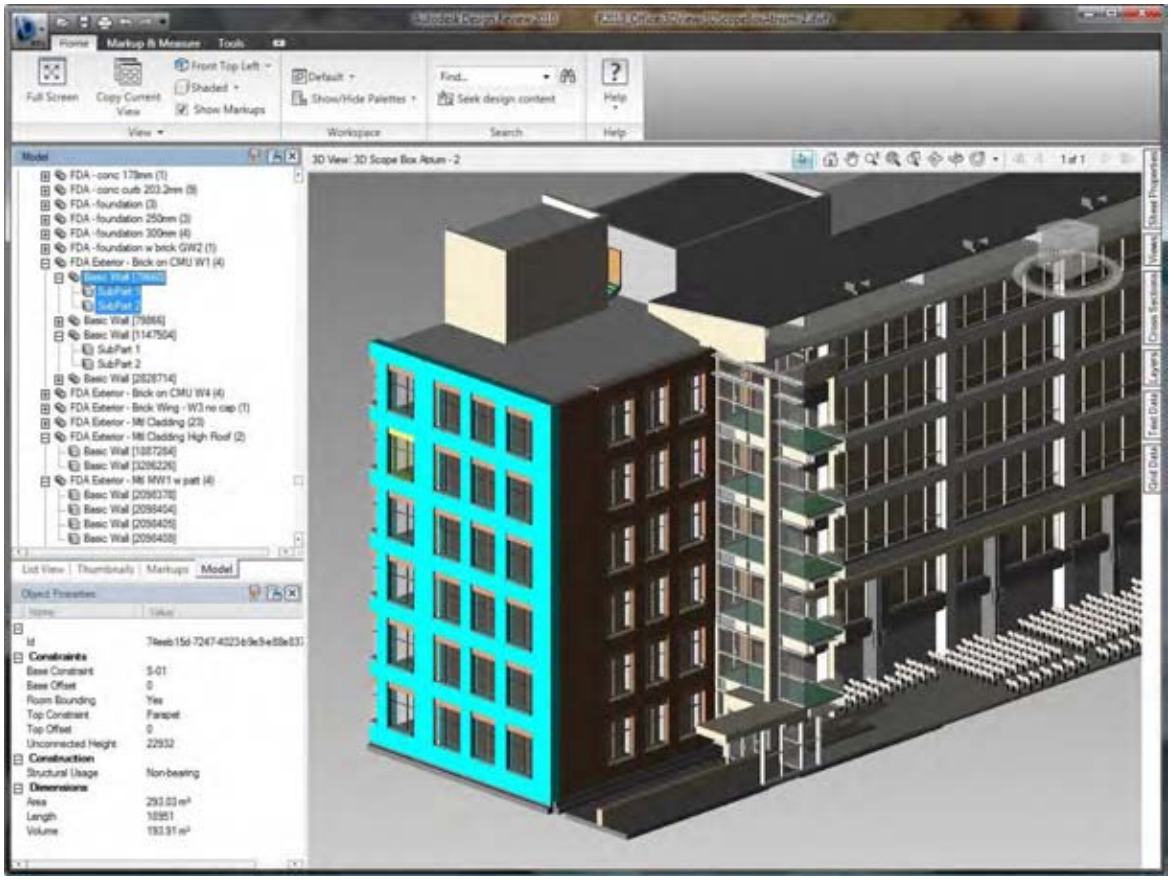


FIGURE 6. A Revit model exported in DWF format being reviewed in Autodesk Design Review.

DISCUSSION

This section discusses some of the key features of Revit Architecture in more detail.

Project Setup

Unlike most of the other BIM applications, there is very little "project setup" required in Revit. The default template for a new project comes with settings for the number of levels, their heights, and plan and elevation views, so it is possible to literally plunge in and start modeling right away. Of course, the default template will almost always be modified based on the project needs, and firms can set up different template files for different project types so that minimal changes need to be made to the settings once a new project is started. Even if changes to the project setup need to be made, the interface is so fluid that they can be made very easily and quickly. For example, adding a level to a project using the Level tool—a simple operation in an elevation view—automatically adds the corresponding views for the new level in both the Floor Plans and Ceiling Plans sections of the Project Browser, as shown in Figure 7. You can now create building elements on this level by simply switching to its corresponding plan view or selecting it as the level for modeling elements in a 3D view. The same task is not as quick and easy in other BIM applications.

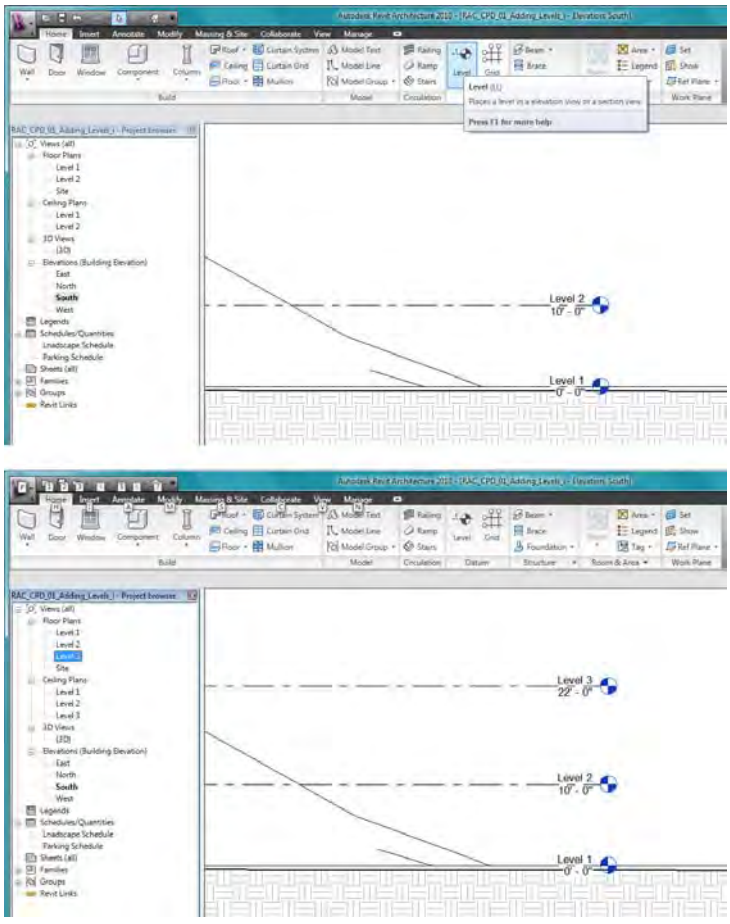


FIGURE 7. Adding a new level in the elevation view automatically creates the corresponding floor plan and ceiling plan views which can then be activated in the Project Browser.

Thus, if you were modeling a 10-storey building in Revit Architecture, you would simply create the levels at the specified height in an elevation view; the application would then automatically create the placeholders for the floor plans at each level for you to model. Elevations, sections, and 3D views automatically show the entire model, and schedules can be created that collate information across the model. Sheets can be created with titleblocks, and can be populated with any 2D or 3D view or schedule by dragging and dropping it from the Project Browser, as shown in Figure 8. By default, all of this information is contained in one project file—referred to as the centralized model approach—and is tightly integrated, so any change made to the model in any view is automatically updated in all views, schedules, and sheets, ensuring consistency. The various building elements are geographically organized in the model according to the floor levels, and this has helped Revit eliminate the need for layers, making it one less thing to worry about when setting up a project.

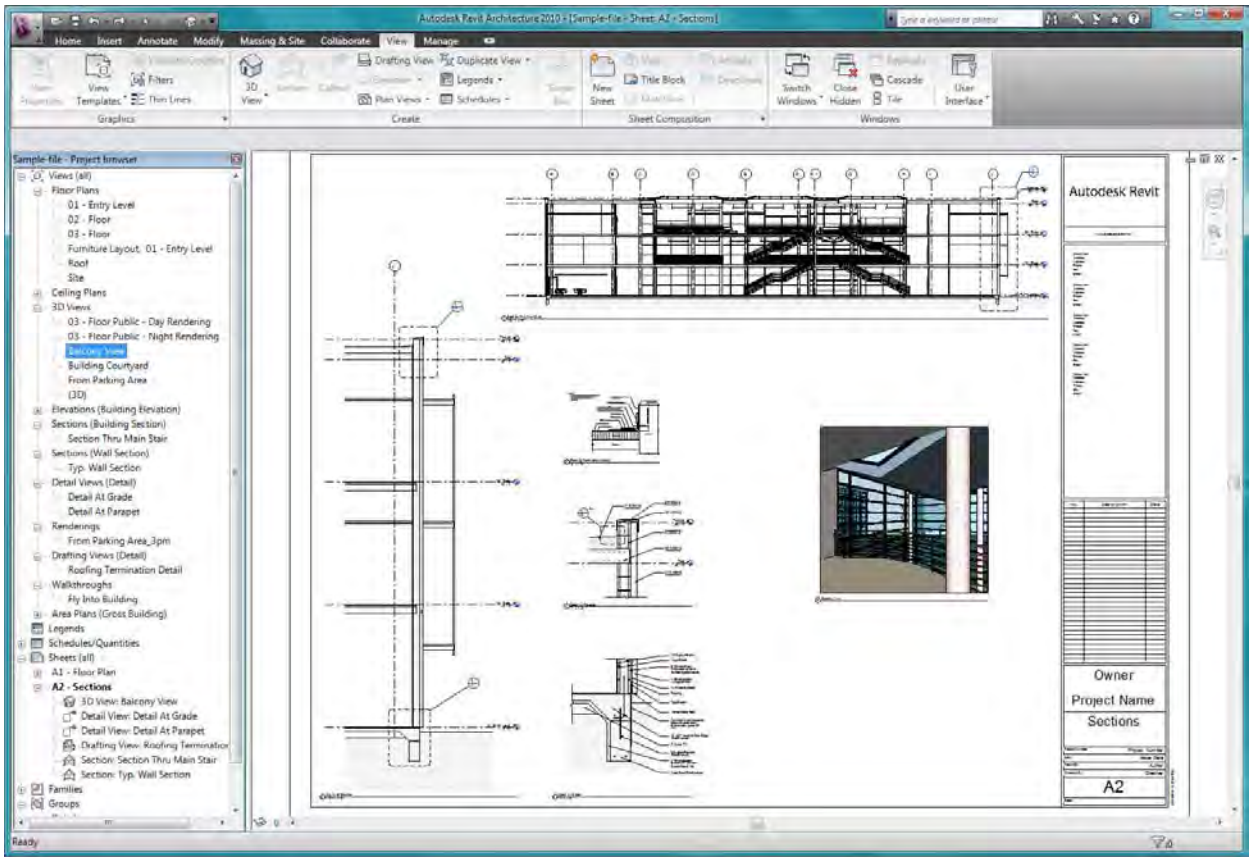


FIGURE 8. Sheets can be easily populated by dragging and dropping views or schedules from the Project Browser.

Since a project in Revit is typically contained in one file, it minimizes the need for complex file management. However, as the project gets larger, it also increases the file size of the model which can slow down the application substantially. For large projects therefore, the model can be divided into multiple project files that can be linked together into a master model. However, this would usually be limited to only a few project files as opposed to the hundreds of files that are typically created in BIM applications which use the distributed model approach. Also, unlike distributed BIM applications where multiple files is the main collaborative approach—with different members of the project team working on different files—the model linking approach in Revit is primarily a means to handle large projects without slowing down the application. Revit has continued to make improvements to file linking to make it easier to use it on large projects; for example, the new 2011 release of Revit allows operations in

a host file to be performed on all linked files as well, essentially allowing the linked files to behave as one consolidated whole (see Figure 9).

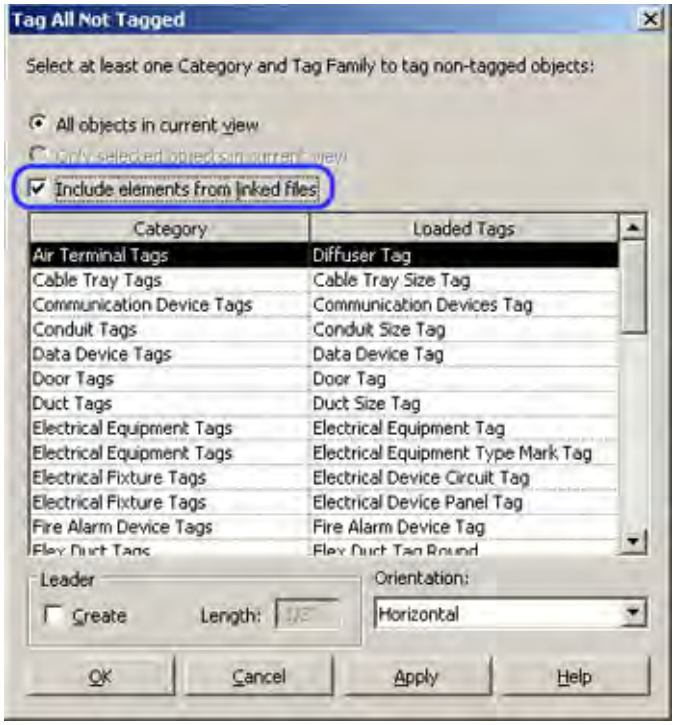


FIGURE 9. New feature in Revit 2011 that allows operations in a host file to be performed on all linked files as well.

For collaboration, Revit has a Worksharing feature that allows multiple team members to work on a Revit project contained in a single file. A central file of the project is automatically created and it works as the master copy, storing the current ownership information for all the elements in the project and acting as the distribution point for all changes published to the file. All users work on a local copy of the central file, make edits to their local copy, and then synchronize with the central file to publish their changes to it. Thus, changes made by others can be seen only when they "check in" their local copies and a user downloads the latest version of the central file to work on.

In earlier versions of Revit, users had to create worksets—which were user-defined element groups—to collaborate on a model, and could check out one or more worksets to work on instead of a local copy of the complete model. However, the checked-out workset was then no longer available to other users for editing and slowed down the collaborative process considerably. It also required advance planning to determine the number of worksets the project would be divided into and the entities that would be contained in each workset, which was not only inflexible but also difficult to manage as more elements were added to the project, as all the new elements had to be properly assigned to the correct workset.

Subsequently, Revit introduced a transparent element borrowing capability, which allowed a team user to edit any project element as long as it had not already been borrowed by another team member for editing. Thus, Revit users no longer need to create worksets except as organizational entities for grouping related elements to make it easier to work with the model, if required. Otherwise, the multiple project team members just work on local copies of the entire model. The transparent element borrowing feature makes collaboration easier by automatically assigning

ownership of an edited element to a user. The ownership is relinquished automatically when the user saves their local copy back to the central file. If a team member needs to edit an element that has been borrowed by another user, they can send an element borrowing request to that user. A Worksharing Monitor allows users to find out if their requests have been granted, as well as find out who is currently working on the project and other related information.

The most challenging aspect of using Revit for collaboration among distributed project teams is the large file size of a project, which creates some latency when users have to save their changes to the central file and download the latest version of the model, particularly when the collaboration is being done over a WAN.

Interface

In Revit Architecture 2010 that was released last year, the interface that Revit had since its launch in 2000 (shown in Figure 11) was replaced by a new ribbon-based interface, popularized by Microsoft in its 2007 Office release, and that Autodesk is standardizing on across all its applications. While it was expected that many existing users of Revit would have trouble with the new interface, at least initially, Autodesk has been barraged with an onslaught of criticism from Revit users for the interface change. Unlike Bentley Architecture, where the interface is fully customizable (Bentley even published a Revit 2009 interface look-alike for its own interface, which will be illustrated in the Bentley Architecture section), the Revit interface is not customizable, so the users are stuck with the ribbon-based interface, even if they do not like it. Not all applications offer the ability to customize the interface—a great example being Microsoft Office itself, whose ribbon-based interface is still unpopular with many of its users—so this cannot be seen as a serious shortcoming. However, it does go to show that Autodesk did not do enough research on the new interface to find out how users would respond to it before going ahead and implementing it.

I personally found Revit's new ribbon-based interface more attractive and better organized—it maximizes screen real estate, can be easily collapsed when required (see Figure 10), and consolidates all tools and options in one location, which would be helpful to new users. But then, I am also one of those users that appreciates the ribbon-based interface in Microsoft Office, which I adjusted to very quickly and found many of the interface enhancements extremely useful. To a certain extent, interface design is a matter of personal preference—there is no magic formula that works for everyone. Applications have to evolve with the times, which often means changing interface features that may be very dear to some users and risk drawing their ire. Users new to Revit will quickly get used to working with the updated interface and will find the old one archaic. But it still points to the fact that Autodesk could do a better job of listening to its users and developing features in response to their requests and feedback.

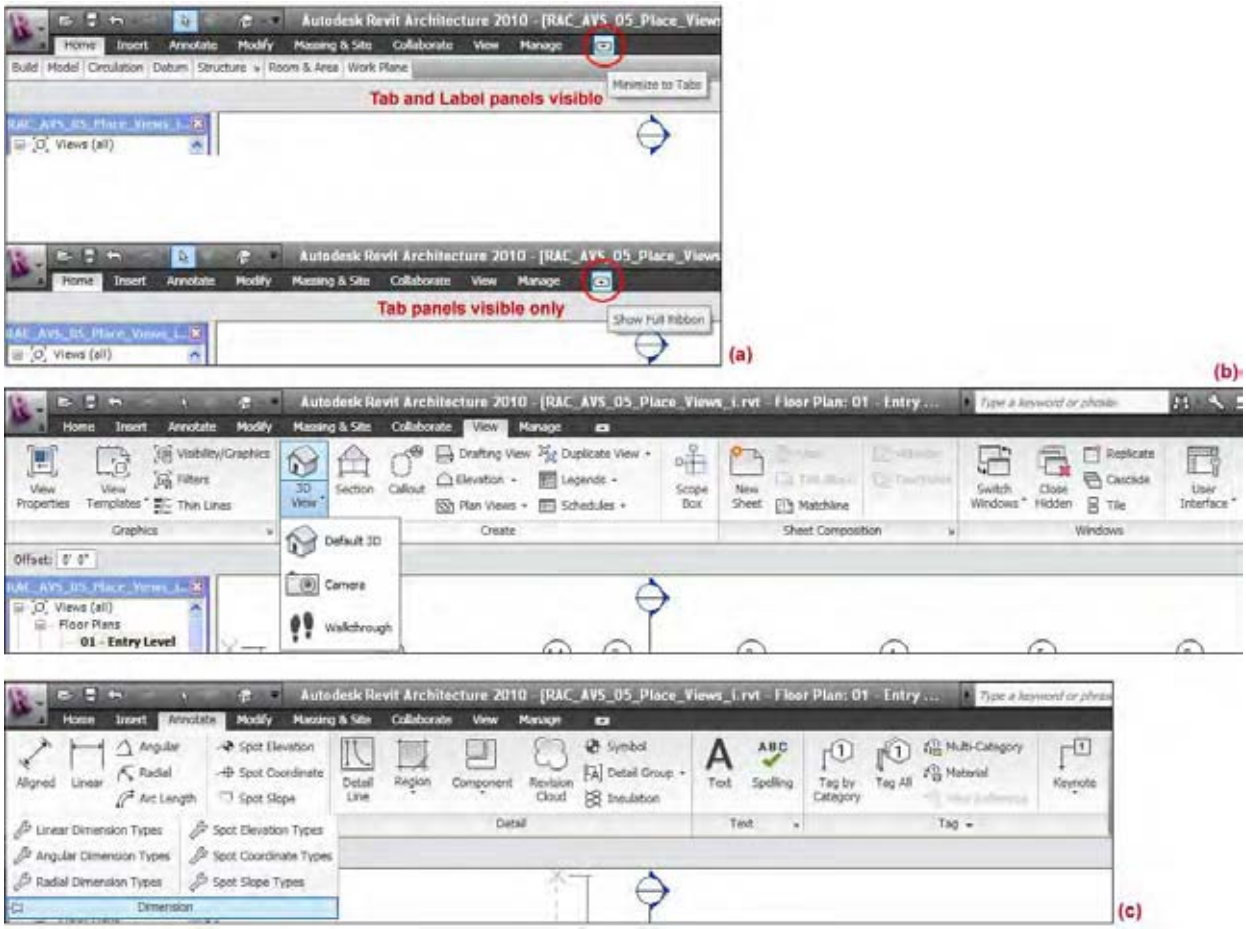


FIGURE 10. Different aspects of Revit's ribbon-based interface introduced in the 2010 release. (a) Toggling the ribbon through different states of visibility. (b) Drop-down buttons. (c) Drop-down panels.

Despite the controversy over the new Revit Architecture 2010 interface, the fact remains that it is still one of easiest BIM applications to learn and use. The ease with which you can get started has already been described in the previous section. Mention must also be made of the Project Browser that provides quick and easy access to all views, schedules, and sheets. It was part of Revit right from the beginning (see Figure 11, which shows a screenshot of the Revit interface taken from my 2004 review of the application). Most of the other BIM applications implemented a Project-Browser like capability only after it appeared in Revit.

Another innovative interface feature that was in Revit right from the beginning is the interactive "heads-up" dimension display that makes it very easy to model accurately, as it not only shows the element dimensions as you are modeling but also key distances and relationships with other elements, allowing them to be overwritten with required values (see Figure 12). Again, this is something that only appeared later in other BIM applications, and is still not implemented in them as well as in Revit.

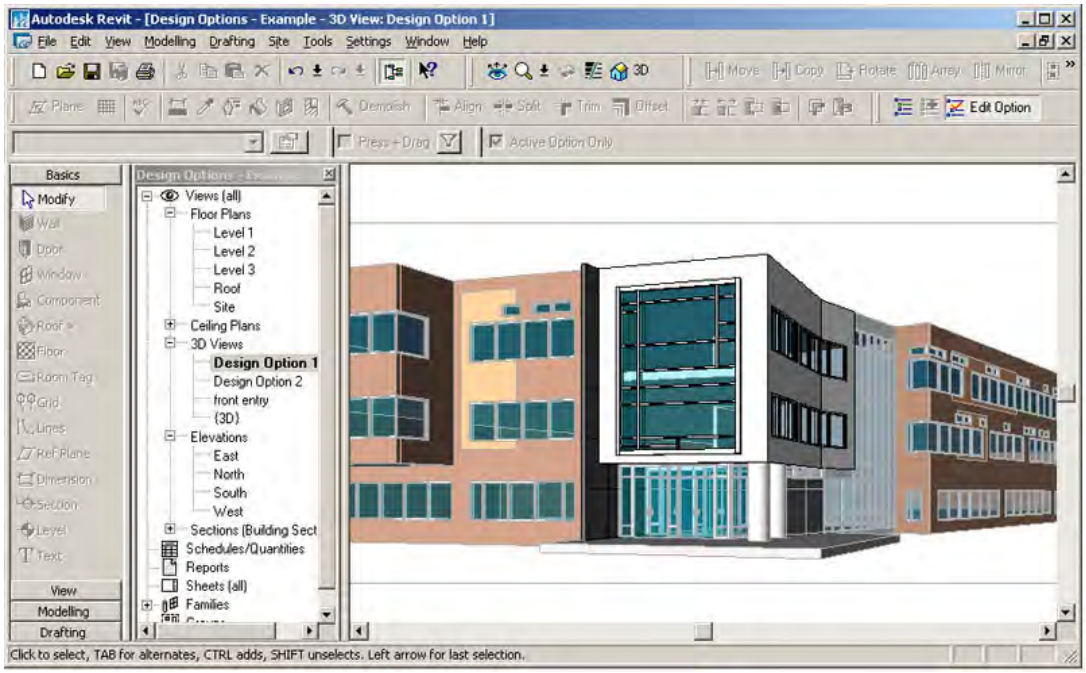


FIGURE 11. A screenshot from a 2004 version of Revit, showing its Project Browser.

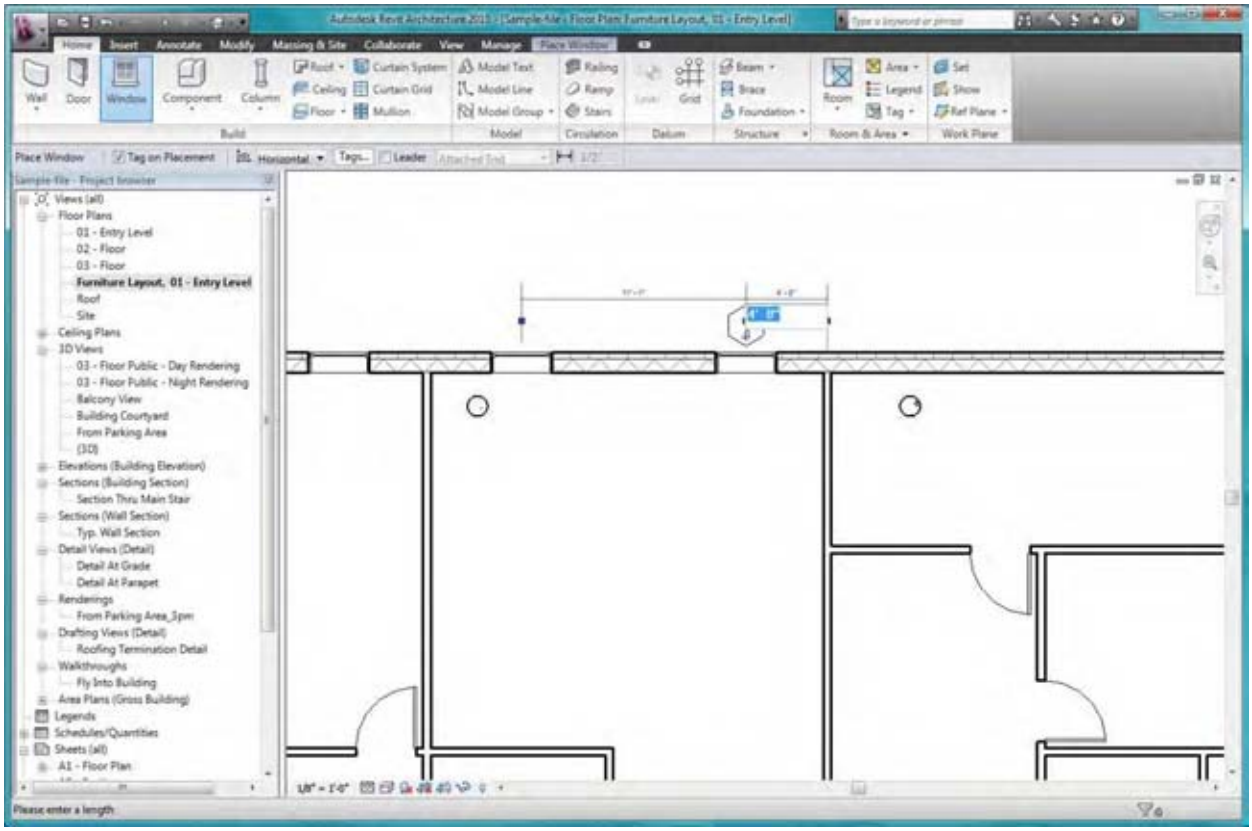


FIGURE 12. Using the heads-up dimension display to accurately place a window in a wall at a precise location from the end of the wall.

Functionality

After many years of poor conceptual modeling capabilities, a concerted effort was made to overhaul these in the 2010 version of Revit Architecture with a new modeling environment, which can be used to create a massing model directly in the project or create a conceptual massing family for commonly used forms that can be loaded into projects. Similar to building elements, massing components can be created with parameters that allow their forms to be easily modified. While the actual modeling interface is not as easy and intuitive to use as SketchUp, it is much more powerful and sophisticated. Instead of having separate tools for creating different kinds of 3D forms from 2D shapes, there is only one Create Form tool which automatically creates extrusions, revolved shapes, sweeps, and lofted forms by intelligently inferencing the source shapes selected. It was used to create both the revolved object shown in Figure 13-a, and the swept object shown in Figure 13-b. The source shape geometry can be tied to reference lines and planes, and subsequently, the form can be quickly modified by simply manipulating the references. Once a form is created, you can further graphically manipulate its individual points, edges, and faces to shape it as required, as shown in Figure 13-c, where the swept shape from Figure 13-b has been modified almost beyond recognition by simply moving some edges.

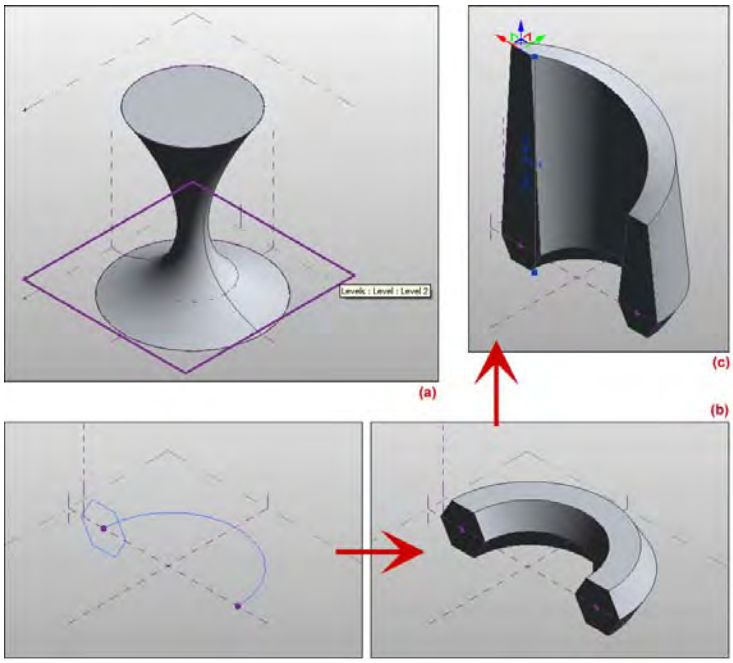


FIGURE 13. The conceptual modeling capabilities introduced in Revit Architecture 2010.

With the use of splines, more complex surfaces and forms can be created, as shown in Figure 14-a. There is also the capability to divide and pattern complex surfaces, to which building detail can be added that can later be fabricated. Figure 14-b shows a Rhomboid Checkerboard pattern applied to the surface created in Figure 14-a, and Figure 14-c applies an actual building panel to the pattern. The panel comes from the family shown in Figure 14-d. The Element Properties dialog for the glass pane in the building panel family is also shown. These curtain panel families behave like regular building components—they can be counted and their materials can be scheduled. With this new capability, very complex curtain systems can be created in Revit, with non-rectangular as well as non-planar panels. They can have parameters that drive their shape in a way very similar to tools like Generative Components or Rhino.

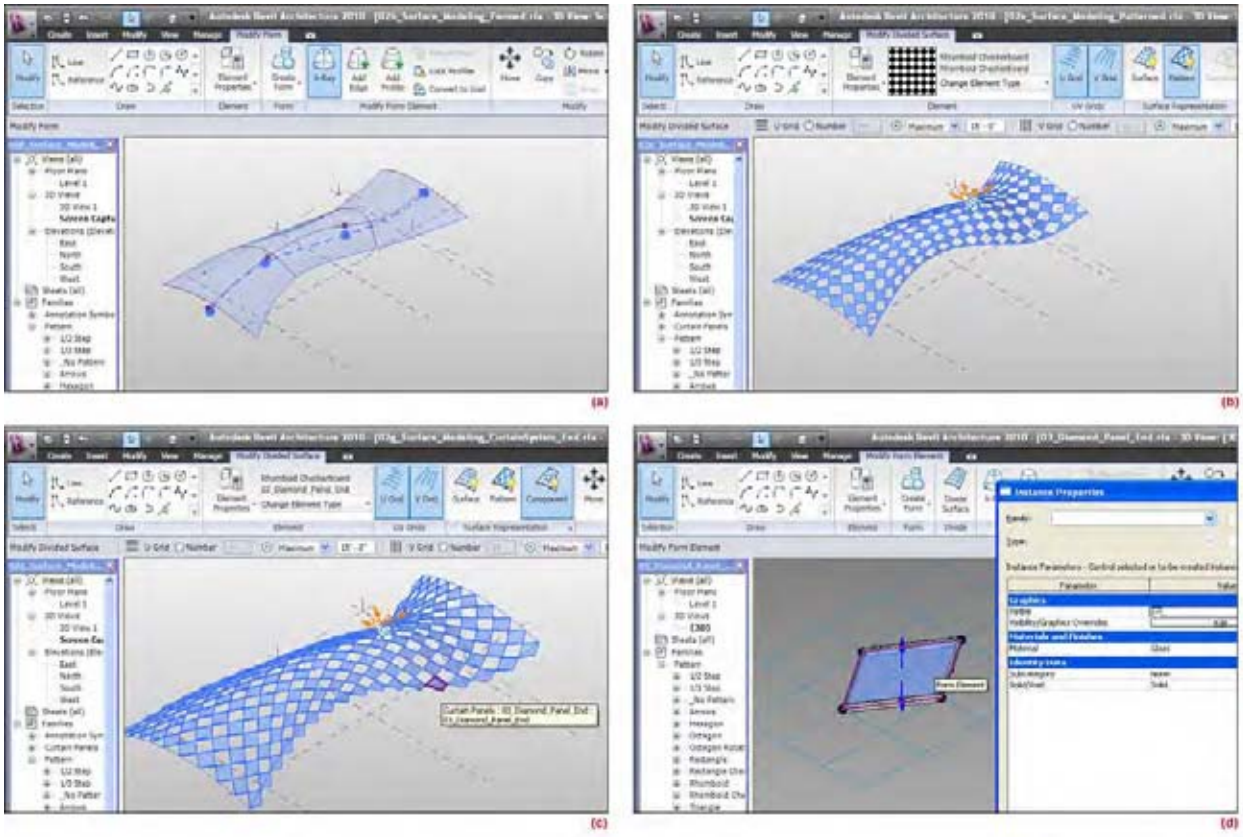


FIGURE 14. Creating a complex surface from a series of spline curves, and subsequently dividing and panelizing the surface to create a curtain panel system.

The heads-up dimension display that shows the dimensions as you are modeling and allows them to be edited—which is so helpful in the detailed modeling stage—also allows conceptual masses to be created to the exact level of accuracy desired. The ability to tie geometry to reference lines and planes, and add constraints and parameters, makes it easy to iterate through many design variations easily and quickly. The ultimate, of course, is the Building Maker capability, which allows the massing model to be converted to actual building elements so that you don't have to start over to create the BIM model, as was shown earlier in Figure 4. This is a capability that none of the other BIM applications have. The scheduling tools available to work with the massing model can allow architects to determine how well the conceptual design would accommodate the programmatic requirements of the project.

For detailed building modeling, Revit has had a good set of tools right from the start. They are similar to those in other BIM applications but stand out in their ease of use. The base settings and type information can be quickly selected in the ribbon interface, and the modeling can be done in plan or 3D views. Elements such as doors and windows can be also placed in elevation and section views if desired. Joints such as wall to wall or column to wall clean up automatically, and the built-in object associativity maintains the connections when elements are moved around. It is also possible to add dimensional and equality constraints to elements, which are maintained when modifications are made, as shown in Figure 15. This level of fluidity enables Revit to be actively used as a design tool rather than merely as a modeling tool for a design that has already been thought out somewhere else.

FIGURE 15. After applying equality constraints to two adjoining walls, any change that is made to one of the walls also modifies the other wall to maintain the equality constraint.

The built-in constraints can sometimes be problematic as they prevent the user from performing certain operations considered to be illegal, which would be allowed in other BIM applications that are not as constraint-based as Revit. Some users might considering this inhibiting and prefer the freedom of other BIM applications that let you model in any way you want. Given Revit's constraints, you would think that it would do a good job of guaranteeing model integrity. Surprisingly, however, it does not and is very inconsistent in what it allows and does not allow. For example, in earlier versions of Revit, you could not place doors and windows that were overlapping with each other; in recent versions of Revit, however, this constraint has been removed, so you can now perform the physically impossible operation of placing doors and windows over each other without any error messages from Revit. Also, despite its claims, Revit is not fully parametric to the extent of an application like Digital Project, where, for example, any change in a driver of building geometry can update the entire model while preserving its integrity. So, for example, moving a wall in a three-storied building model moves it on all three floors, but it does not stretch the floor slabs or the roof to maintain their connections, as shown in Figure 16.

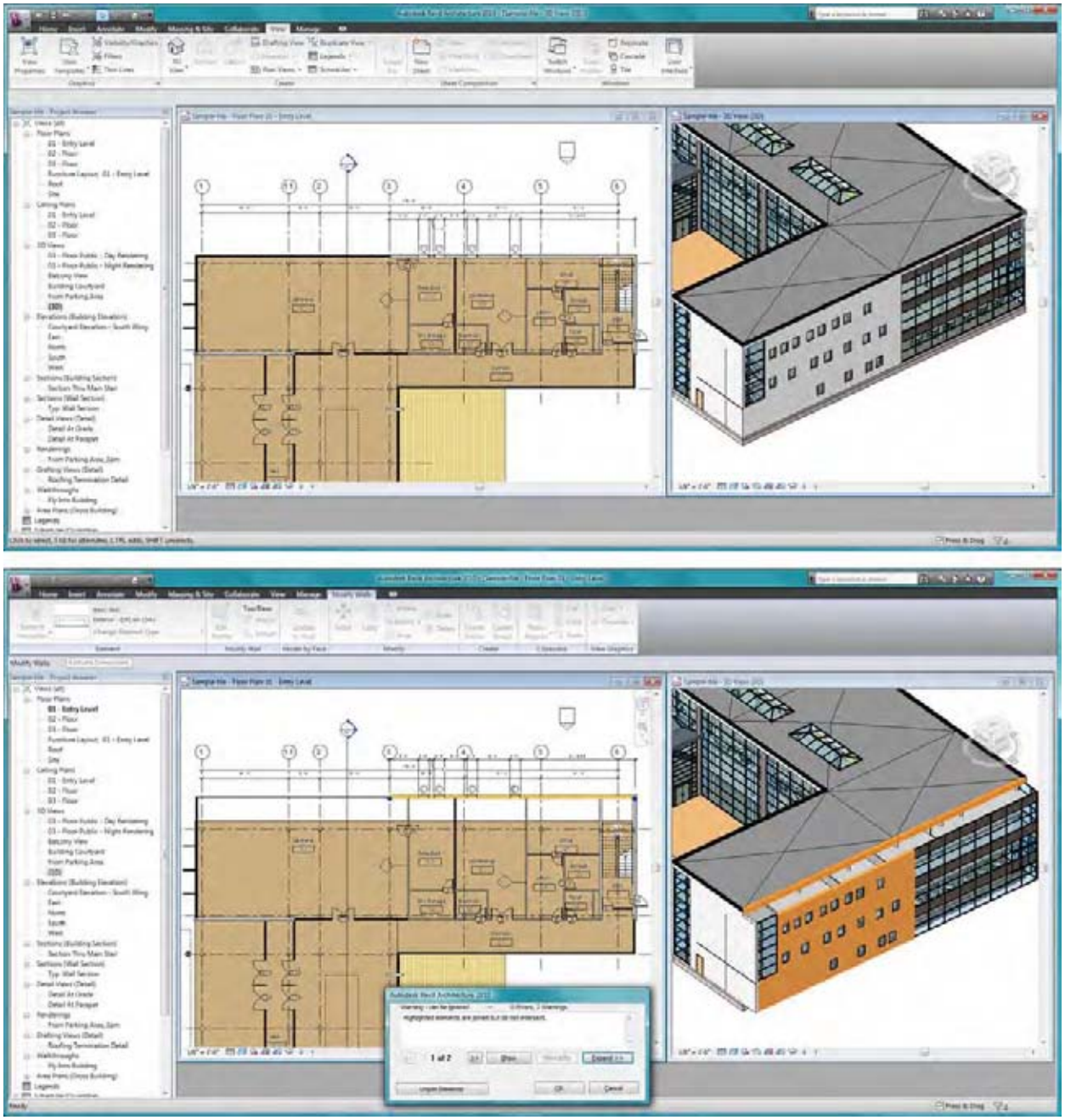


FIGURE 16. The effect of moving a wall in Revit Architecture. The modification is shown in the lower image. Revit provides you with a warning about the "unjoining" of elements that were earlier joined, but does not automatically stretch the roof or floor slabs to keep them connected to the walls.

Some other noteworthy aspects of Revit's functionality include a Design Options feature that allows multiple design alternatives for different parts or aspects of the design to be created within the same file, enabling the team to more easily explore, evaluate, and present them (see Figure 17). For rooms with irregular heights, Revit is unique in being able to correctly display the non-uniform volume in section views as well as calculate the volume accurately (see Figure 18). Also, while Revit's display capabilities are not as visually pleasing as some of the other BIM applications, it includes functionality such as being able to create user-defined filters to override the graphic

appearance and visibility of all elements that share common properties in a particular view. Figure 19 shows an example where three different filters have been defined for three different fire rated walls, which are then used to differentiate the walls with different colors in a floor plan.

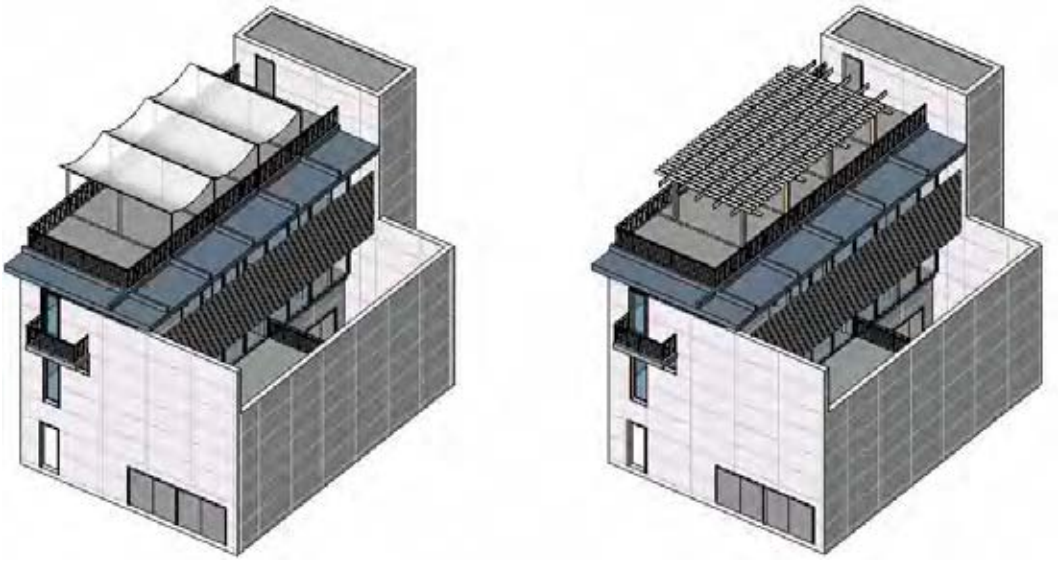


FIGURE 17. Design Options was used to model two alternate roof covering options for this structure in the same file.

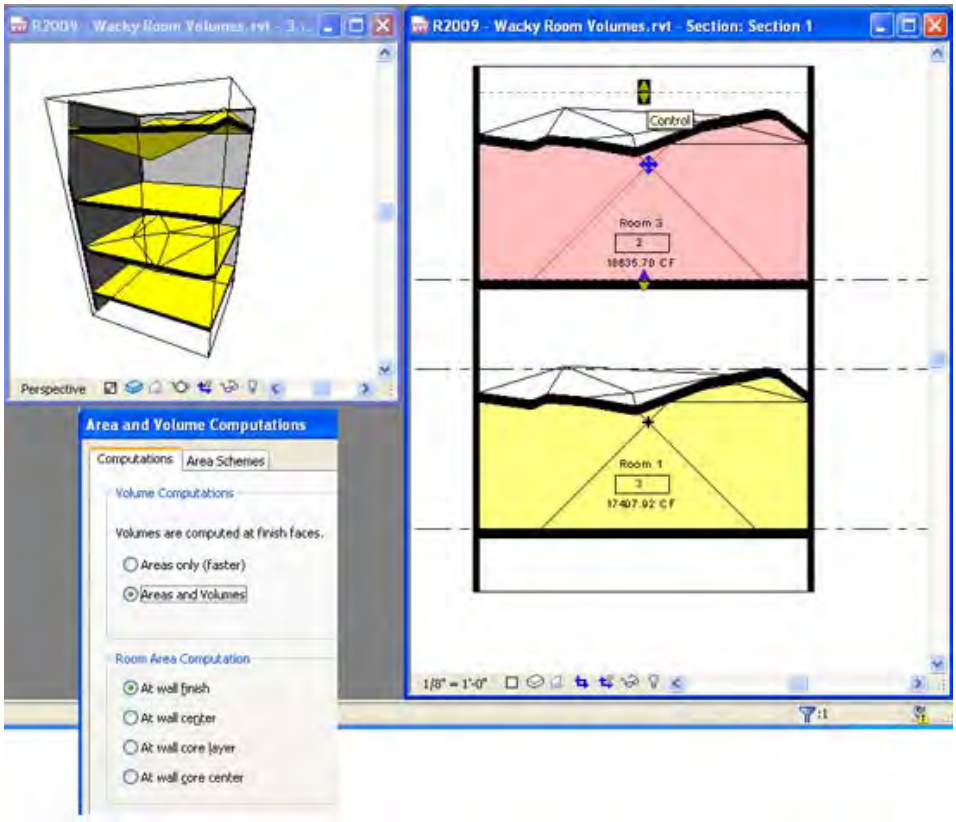


FIGURE 18. Accurate volume display and calculation of non-uniform room volumes in Revit.

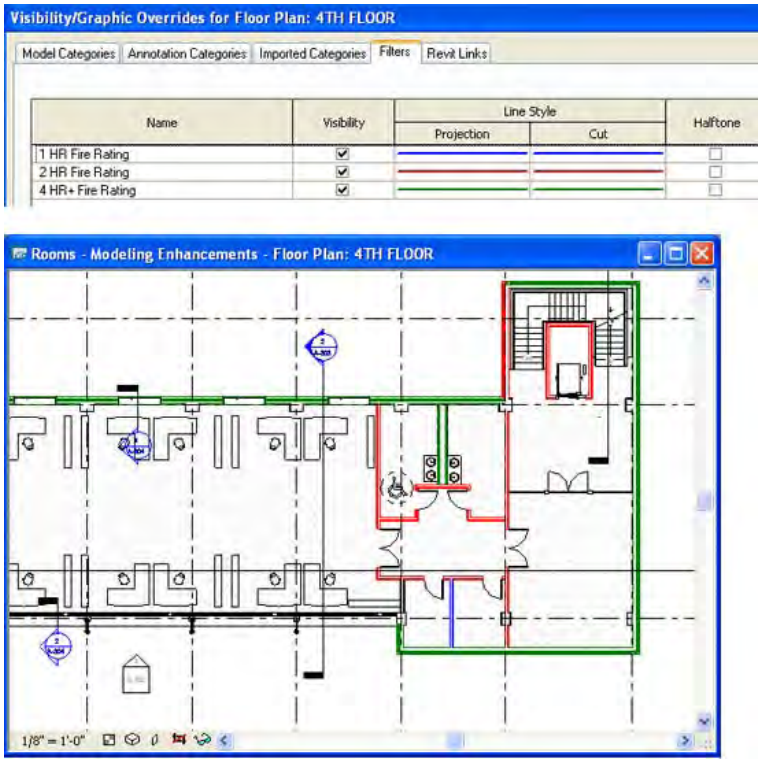


FIGURE 19. Defining separate colors for walls with different fire ratings in a floor plan. The filters for the three different wall types based on fire rating had been previously defined.

CONCLUSION

The reasons for Revit's popularity and success among architectural firms are not hard to fathom. Since it was developed from the ground up with the BIM concept, it has a definite edge in facilitating the process of BIM over most of its competitors that were developed much earlier on as CAD applications and have now added BIM capabilities. Its automated project setup allows a user to start modeling right away and put together a simple project in a matter of hours rather than days. Its intuitiveness, built-in object associations, and overall ease of use make it a pleasure to work with rather than a chore. It is well suited to being actually used as a design tool rather than just for post-design modeling.

This does not imply in any way that firms using other BIM applications are at a disadvantage and need to switch—they may have mastered the use of their application and could be doing BIM that is comparable, even superior, to that being done by firms using Revit. But the fluidity and ease of use that Revit brings to the BIM process makes it hard not to consider its usability as a benchmark for evaluating other BIM applications and finding them lacking in this aspect.

While Autodesk has done well to bring Revit to the point where it is now a platform for multi-disciplinary BIM applications rather than a single disciplinary solution, it has also failed to address the critical problems of file size and collaboration that Revit users are facing, especially those working on large projects with distributed project teams. All of the other BIM applications are currently better at addressing these issues, even ArchiCAD, which shares Revit's centralized model approach. Other aspects that Revit could improve upon are its parametric and

change management capabilities, which, while being better than most of the other BIM applications, are a fry cry from the sophisticated parametric technology of Digital Project. While Revit may be "smart," it is not yet smart enough to disallow illegal operations and guarantee a conflict-free model, even within a single disciplinary architectural model.

Looking at Autodesk's overall approach to its technology development, the last few years haven't inspired much confidence. It has discontinued several good AEC applications, including the highly regarded Autodesk Architectural Studio, the nifty little Autodesk Impression, and the BIM-enabled FMDesktop for facilities management. The last one was especially surprising, as it comes at a time when the other BIM vendors are, in fact, actively developing the FM component of their applications; instead, Autodesk chose to discontinue its in-house FM application, and outsource it to a third party vendor. While economic considerations clearly had some role to play in these decisions, they seem to be indicative of some "hit and miss" thinking within Autodesk, pointing to a troubling lack of a clear strategic plan for new products and of long-term planning and foresight. In addition, the AEC division of Autodesk has been through a lot of shuffling and reorganization lately. All of these, coupled with the Revit 2010 interface fiasco, have weakened the reputation and image of the company. Autodesk needs to show evidence of some serious innovations in upcoming releases if it wants to maintain Revit's current lead as the BIM application of choice for architectural firms in the US and worldwide.

Bentley Architecture

Bentley Architecture is developed by Bentley Systems, a family-owned, privately held company that celebrated its 25th anniversary last year. Three of the five Bentley brothers who founded it continue to stay actively involved in leading the company. Starting with its flagship CAD application, MicroStation, the company moved on to develop MicroStation-based applications for four core verticals—Civil, Building, Plant, and Geospatial. In recent years, Bentley has diversified its offerings to serve many more categories including Bridges, Buildings, Cadastre and Land Development, Campuses, Communications, Electric and Gas Utilities, Factories, Mining and Metals, Oil and Gas, Power Generation, Rail and Transit, Roads, and Water and Wastewater. It has over 100 products in its portfolio, and these are being used on some of the biggest infrastructure projects around the world (see Figure 1). The company has spent over $1 billion on acquisitions and R&D since 1995, with close to 50 acquisitions in the last five years alone, including key ones in AEC such as RAM and STAAD for structural analysis, Hevacomp and Tas for energy analysis and building services design, and ConstructSIM for construction simulation. It now has 2,700 employees around the world, of which 58 hold doctoral degrees and 564 hold masters-level degrees. It is no mean achievement that a private company has not only survived but continued to grow steadily despite the presence of large competitors such as Autodesk and Intergraph in AEC and other infrastructure industries. Bentley's annual report shows its revenue continuing to rise despite the economic downturn; it crossed the $500 million milestone in 2008. There should be little doubt about the stability and long-term viability of the company—it seems to be in sound financial health with great long-term prospects.

FIGURE 1. A snapshot of the range of infrastructure projects that have been designed using Bentley solutions.

Bentley Architecture is part of a multi-disciplinary suite of BIM applications that also includes Structural Modeler (formerly called Bentley Structural), Bentley Building Mechanical Systems, Bentley Building Electrical Systems, and Bentley Facilities. Complementing these and extending their capabilities are a number of other Bentley

applications: GenerativeComponents, a sophisticated, parametric, generative design application that has been successfully used by some of the world's leading design firms; ProjectWise, a project management and collaboration platform; ProjectWise Navigator, a Navisworks-like application for multi-disciplinary design coordination and review; the RAM, STAAD, Hevacomp, and Tas analysis tools and the ConstructSIM application for construction simulation mentioned earlier; ProSteel, a structural detailing application; and civil engineering and site design tools include GEOPAK, Inroad, and Bentley Map.

Bentley's approach as a software developer has some key differentiating factors from its largest AEC competitor, Autodesk. It follows a layered approach to software development, with all of its applications across all disciplines being built on top of its two main platform products, MicroStation and ProjectWise. This allows the advances in its platform products to be leveraged across all disciplines, providing continuous improvement as opposed to drastic changes. It also enables consistency of user experience and data formats across all the applications and allows them to work together easily when required, facilitating collaborative multi-disciplinary design. Thus, the structural and MEP components of a building, designed using Bentley's structural, mechanical, and electrical applications can be seen and queried in Bentley Architecture, without requiring the original applications to be installed (see Figure 2). Similarly, the entities created in Bentley Architecture can be viewed and queried in the other applications and used as the basis for structural and MEP design.

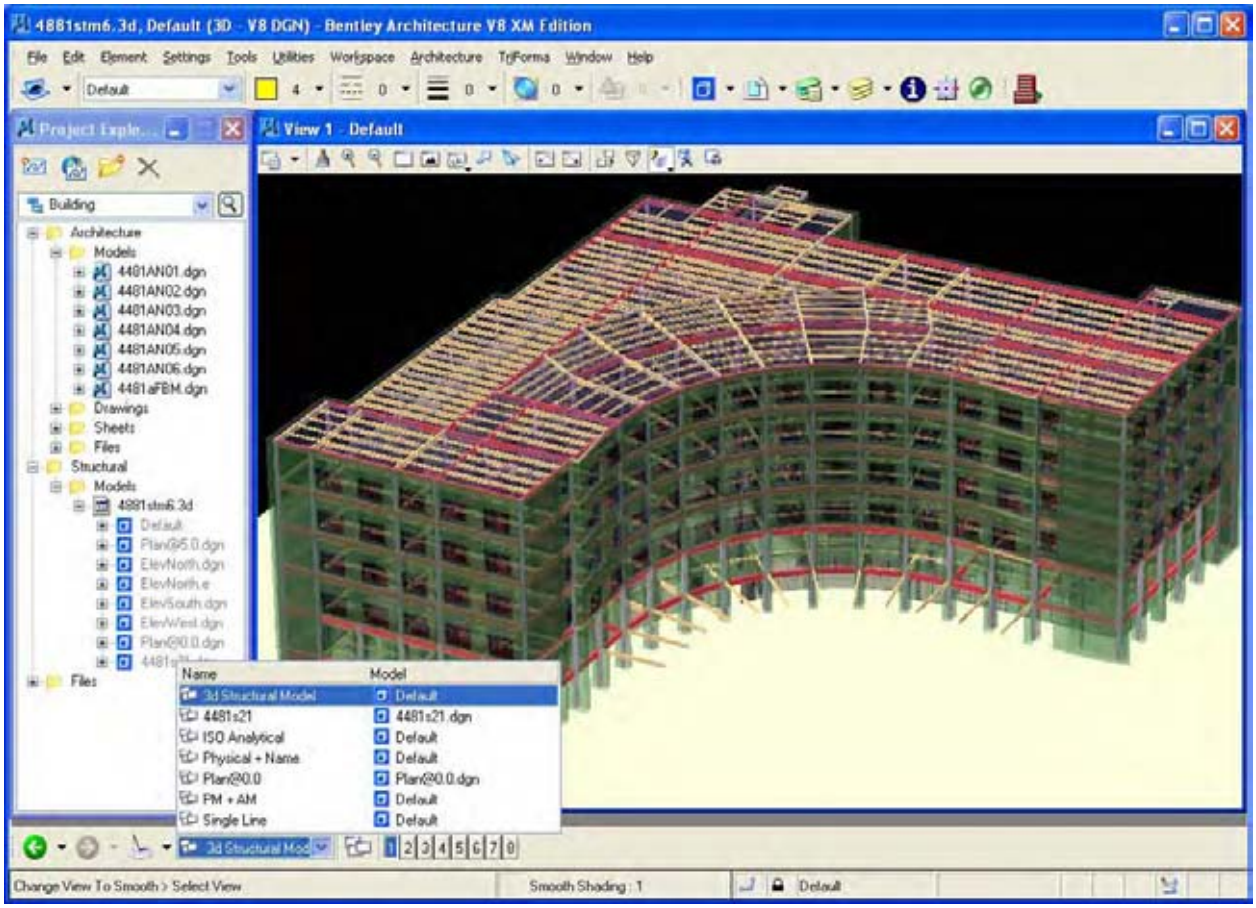


FIGURE 2. Viewing the structural model of a building, created using Bentley's structural BIM application, within Bentley Architecture.

In addition, Bentley maintains the position that workflows in all the infrastructure disciplines are separate despite being eventually integrated, and therefore has a federated approach to BIM, where the model is distributed across multiple files as opposed to being centrally located in one model. The master model is assembled by using references to link all the individual model files. While this enables Bentley solutions to be used for large and complex projects in the same way as it can be used for small ones, it has the disadvantage of greatly increasing their complexity, with the distributed file structure making project organization difficult to set up and manage.

And finally, interoperability is considered critical and is achieved by supporting open standards such as the IFC, publishing to standard formats such as PDF, by direct read/write of popular formats such as DWG, and connecting with applications through APIs. Bentley has also recently introduced a new concept called the "i-model" intended to facilitate open information exchange between infrastructure applications. It would allow multiple files in different formats from different vendors, not just Bentley, to be consolidated into an i-model that will be optimized for different tasks such as project coordination and review, structural modeling and analysis, energy analysis, material estimating, data handover, etc. The i-model retains all the object geometry and attribute information created in the original authoring application. While all the Bentley BIM applications already have the capability to create an i-model and a free plug-in is also available to create i-models from external applications like Revit, this initiative is still too new for its success and overall impact in the industry to be gauged.

EVALUATION SUMMARY

Key Strengths

- Inherits all the power and comprehensiveness of MicroStation's CAD platform in solid and surface modeling, documentation, rendering, and animation
- Is part of Bentley's multi-disciplinary BIM platform, facilitating cross-disciplinary coordination
- Integrates with Bentley's extensive portfolio of analysis tools and infrastructure design applications
- Federated approach to BIM lends itself much more easily and efficiently to distributed work processes and large projects
- Greatly improved conceptual design capabilities in the last few releases
- Enables complex geometry to be created to which BIM information can be added
- Integration with GenerativeComponents enables sophisticated rule-based form-making capability
- Integration with ProjectWise provides more structured project management and collaboration capability
- Integrated Luxology rendering engine allows high-end renderings and animations to be created within the application
- New display styles allow high-quality presentation graphics to be easily created
- Very strong on interoperability, with many supported file formats, including native support of Rhino and SketchUp files with live links
- Senior management, and company as a whole, is very technology-focused
- Bentley has continued to survive and thrive despite the dominance of larger competitors like Autodesk

Main Limitations

- Complex application with a steep learning curve
- Since it is built on top of MicroStation, it requires the user to also master that application in addition to Bentley Architecture before being able to use it effectively
- Distributed project structure is difficult to set up and manage, with too many constructs to work with
- Model is distributed across multiple files, so real-time collaboration is not possible
- Limited object intelligence (associativity) and change management capabilities, especially across files
- No modeling constraints, so no assurance of model integrity
- Lagging behind in support of multi-processing and 64-bit
- Quality of the documentation is poor, making it even more difficult to learn the application
- The "Buildings" segment is becoming an increasingly smaller part of Bentley's product portfolio, raising doubts about the company's focus on this industry and more specifically on architecture

Price

- List price for Non-MicroStation users is $6,290 (includes MicroStation, passport for ProjectWise Navigator, Parametric Cell Studio, Space Planner and Bentley Architecture)
- MicroStation users can add Bentley Architecture for $1,495
- New Passport License is $2,295 per year

DETAILED EVALUATION

Application Repertoire

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Space Planning/ Programming		✓		Includes basic space planning capability, allowing a list of spaces from a spreadsheet to be imported and used to explore different spatial layouts. These are not as comprehensive as those of a dedicated space programming application like Trelligence Affinity, and there is no integration with Affinity either. Also, there are no capabilities for bubble diagrams, adjacency matrix, and space links with scores, similar to what Vectorworks provides.
Conceptual Design/ Mass Modeling	✓			Recent improvements in conceptual design capabilities, including a SketchUp-like Push/Pull feature and the ability to divide a face by simply drawing on it, makes it easier and more intuitive for creating massing models. While conceptual modeling is still not on par with SketchUp, it is the best of all the BIM applications.
Detailed Modeling	✓			Has an extended toolset for modeling the site as well as different building components such as walls, curtain walls, doors, windows, columns, ceilings, floors, stairs, and so on.

Schedules and Reporting	✓			Includes a DataGroup system which is used to manage building objects, both built-in and user-defined, add custom attributes to them if required, and generate schedules and other needed reports.
Quantity Take-off	✓			Includes a Quantity Takeoff tool that can extract quantity information from a 3D model and export it in the form of spreadsheets or databases. There are built-in templates to create the spreadsheets or users can create their own.
Photorealistic Renderings	✓			Integrated Luxology rendering engine allows highly photorealistic renderings to be created right within the application. (*See Figure 3*)
Animations	✓			Luxology rendering engine also enables high-quality animations to be created within the application, with features including key frame and time-based animation, live on-screen animation preview, timeline and velocity graph, and distributed/networked rendering.
Real-time Model Exploration		✓		Includes the standard modeling navigation tools and a powerful dynamic sectioning capability. However, advanced navigation options and real-time model exploration are only available in the separate Project Navigator application.
Construction Documents	✓			Inherits the extensive range of dimensioning and annotation tools available in MicroStation. A new "dynamic views" capability allows drawings to be live views of the model that are automatically updated when the model is changed. A dedicated Print Organizer application is available that streamlines publishing workflows to reduce manual steps, and improves plot quality and consistency. (*See Figure 4*)
Coordination/ Clash detection		✓		No built-in capability; however, another Bentley application, ProjectWise Navigator, can be used for multi-disciplinary design coordination and collaborative review, with capabilities for clash detection, walking through the model, measuring and querying objects, as well as augmenting the information contained in the model. (*See Figure 5*)
Fabrication		✓		Geometry information can be exported for fabrication in Excel, CSV, or STEP formats.

Intrinsic Nature and Capabilities

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Intuitiveness and Ease of Use			✓	Despite the availability of customizable task-based interfaces and a feature called Accudraw that allows precise and detailed modeling, the overall application is still very complex. Users need to master MicroStation before being able to use Bentley Architecture effectively, which in itself is a vast and complex application.
Ease of Project Setup			✓	Because of the distributed modeling approach, project setup is very complicated to set up and maintain. There is no fixed way to divide up the project, and no automatic setup for the different levels of the project, as there is in all the other BIM applications, even those that use the distributed approach like Allplan and Digital Project.

Information Re-Use		✓		Spaces can be converted to walls when going from space planning to detailed design. However, Bentley Architecture lacks the capability to automatically derive the building shell—with intelligent wall, floor, and roof "BIM" objects—from a schematic massing model. So the effort spent in developing a massing model cannot be effectively directed towards jumpstarting the detailed design process.
Modeling of Organic Building Forms	✓			Inherits the full range of sophisticated solid and surface modeling tools in MicroStation that can be used to model any kind of freeform object to which building attributes can then be attached. The integration with GenerativeComponents allows even more complex and sophisticated forms to be created and assigned with BIM attributes.
Automation of Tasks		✓		There is no built-in task automation; however, both GenerativeComponents and Parametric Cell Studio, a separate utility, can be used to create rule-based parametric forms and objects. (*See Figure 6*)
Creation of Parametric Forms	✓			Can be integrated with GenerativeComponents, which uses rules and parametric technology to drive the generation of complex forms, allowing many design variations to be explored. Parametric Cell Studio can be used to create simpler parametric objects. (*See Figure 7*)
Associative Behavior of Building Elements			✓	Limited amount of object associativity and intelligent behavior, especially as the model is distributed across multiple files. Changes to related building elements resulting from a modification to an object are not propagated across files.
Guarantee of Model Integrity			✓	Very few modeling constraints to guarantee model integrity—walls can overlap with other walls, doors and windows can be moved out of walls, doors and windows can overlap with each other, and so on.
Availability of BIM Content		✓		Comes with a lot of BIM content (over 1000 architectural objects) localized for different parts of the world; however, most of this content is created by Bentley rather than by third party developers. Bentley has recently launched a Content Partner Program, but currently this is only focused on MEP content.
Customization Capability	✓			Comes with task-based interfaces that can be fully customized. Additional customization can be done through a rich API, which has been available for years.
Support for 3D Printing	✓			Includes support for stereo lithography, laser printers, and 3D printers. It can directly send models to some 3D printers like ZCorp without the need to export to the STL format.
Multi-Processing Support		✓		Only the Luxology rendering engine makes use of the multiple cores on a computer to speed up rendering.
64-bit OS Support			✓	The application is only 32-bit at this time.
Cross-Platform (Windows, Mac)			✓	Bentley Architecture is a Windows-only application.

Issues Specific to Large Firms

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Model Performance		✓		Since the model is distributed across multiple files, the performance is not as slow for large projects as it is for centralized BIM applications. However, there are no special capabilities to speed up performance when the master model of a large project is opened up with all its reference files.
Model Sharing Technology		✓		Bentley's ProjectWise can be used as a project management and collaboration platform. While this does not allow for real-time collaboration of the kind ArchiCAD's BIM server enables, it provides a structured way for the project team to access and share project files from anywhere in the world, with security, document versioning, automatic revision versioning, enforcement of file naming standards, SharePoint integration, and many additional features.
Support for Distributed Workflow		✓		The federated approach makes it easier for a distributed team to work on a project. The use of ProjectWise provides a managed environment and enables more efficient collaboration across distributed teams; however, the collaboration is still not real-time.
Security and Access Controls		✓		Basic controls are provided by the operating system. Any additional security and document management capability is available through the ProjectWise collaboration platform.
Performance Across WAN	✓			Incorporates techniques such as caching and delta file transfer, where only the changes are detected and sent rather than the entire file. This helps to reduce bandwidth dependency.
Ability to Handle Large Projects	✓			Since the building model would typically be broken down into a large number of files, it allows for very large projects to be modeled and to a high level of detail.

Interoperability

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Integration with Structural BIM Applications	✓			Includes direct integration with Bentley's in-house structural BIM application, Structural Modeler. Integrates with other structural applications through IFC.
Integration with MEP BIM Applications	✓			Includes direct integration with Bentley's in-house Building Mechanical Systems and Building Electrical Systems applications. Integrates with other MEP applications through IFC.
Integration with Sustainable Design Tools	✓			Closely integrates with Bentley's Hevacomp and Tas energy analysis tools; also supports gbXML for analysis in other leading sustainable design applications including IES, Ecotect, Green Building Studio, EnergyPlus, DOE-2, TRACE, and others. Lighting analysis can be done with the Visual suite of tools from Acuity Brands, and this information can be round-tripped back into the BIM model.

Integration with Estimating Applications		✓		Exports quantity take-off information in Excel and CSV formats that can be used for estimating, but it does not directly integrate with any established estimating tool. However, it does include a built-in pricing tool.
Integration with Constructability Tools	✓			Directly integrates with ConstructSIM, Bentley's in-house construction planning and simulation tool, and with ProjectWise Navigator for coordination and review. Fabrication information can be exported in Excel or CSV formats. Can import, export, and linking to schedule information managed in Microsoft Project, Excel, or Primavera Project Planner.
Electronic Publishing and Review	✓			Publishes 3D PDF files, with enhancements such as the ability to search for metadata, links from the objects to specifications, rich object properties, and saved views. An entire project including 3D models, 2D drawings, specifications, and other documents can be packaged in a single PDF document. Also integrates with Bentley's Dynamic Plots capability which automates electronic mark-ups by using pen and paper.
Range and Quality of Third-Party Tools			✓	Relatively few third party vendors are developing add-on tools or extensions for the application, despite the availability of the API.
Number of 3D File Formats Natively Supported	✓			Supports a wide range of file formats including DWG, DXF, IGES, Parasolid, STL, STEP, Collada, VRML, ACIS SAT, and others. It can directly read competing file formats such as DWG, directly open SketchUp and Rhino files and maintain live links to them (*see Figure 8*), and exports models directly to Google Earth. A free plug-in for Revit is available to create an i-models which can then be imported or referenced into Bentley Architecture.
Quality of API	✓			Includes an extensive API that allows users and developers to utilize the majority of the functions and features to customize the application and develop specific programs and add-ons.
IFC Support	✓			Strong focus on interoperability makes Bentley very committed to the IFC standard.

Implementation

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Initial and Ongoing Pricing/Licensing		✓		Pricing is on par with Revit and ArchiCAD. There are two main update and support subscription programs, SELECT for individuals and small firms (fixed fee per license) and ELS for large firms (unlimited access to all Bentley applications for a fixed annual fee). Newly introduced "country-level license pooling" enables project teams to share Bentley software and resources across all offices within a country, enabling more efficient utilization and flexible allocation of resources. A new "passport license" provides full access to software, training, and support for a lower-cost fixed annual fee.
Initial and Ongoing Training		✓		Has a Bentley Institute that provides both live training and online learning courses, and a Bentley LEARN program that provides unlimited on-demand eLearning for a fixed annual fee. Free training opportunities are limited.

Quality of Technical Support	✓			All the subscription options provide full 24/7 access to phone support at no additional charge as well as access to a large collection of online on-demand learning opportunities.
Quality of Included Documentation			✓	Quality of the documentation is poor and insufficient to learn the application. A QuickStart Guide is available, but it covers only very basic aspects of the program; it does not provide guidance on how to set up and structure a project across multiple files, how to create multiple levels, etc. A users needs to also study the separate documentation of MicroStation to understand how to use Bentley Architecture properly.
Free Online Learning Resources		✓		There is some training material, including podcasts, available online. Also, "BE Communities" has been set up as a social networking site, which includes forums, blogs, resource galleries, and wikis that can allow users to connect, communicate, and learn from each other. However, it is still a struggle to find good training material that provides a comprehensive overview of how the application works.
Support Channel (Resellers and Consultants)			✓	Does not have a reseller channel; you have to buy the software and related services directly from Bentley. It includes a large Professional Services group to provide consultation services.
Availability of Trained Staff		✓		Bentley has a BE Careers network that helps its users find employment as well as assists firms looking for Bentley experts. Also, it makes the software available to schools for free. However, it is still much easier to find Revit experts than Bentley experts.

Vendor

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Current Market Position		✓		In the Building industry as a whole, Bentley is still trailing behind Autodesk. Looking specifically at usage among architectural firms, Bentley Architecture is trailing behind both Revit Architecture and ArchiCAD. Bentley's position is a lot better in engineering firms.
Long-term Viability	✓			Since its start 25 years ago, Bentley has been continuously growing in the number of industries it serves (13), the number of applications it develops (over 100), the number of employees it has (over 2,700) and its revenues (over $500 million annually).
Investment in R&D	✓			Bentley has invested over $1 billion on acquisitions and R&D since 1995.
Responsiveness to Feedback and Requests	✓			The company is continually communicating with its users and soliciting their feedback and inputs through its *BE Communities* forums. Bentley has a user council of 20-25 companies around the world that it communicates with regularly for feedback.

FIGURE 3. Examples of renderings created using the integrated Luxology rendering engine.

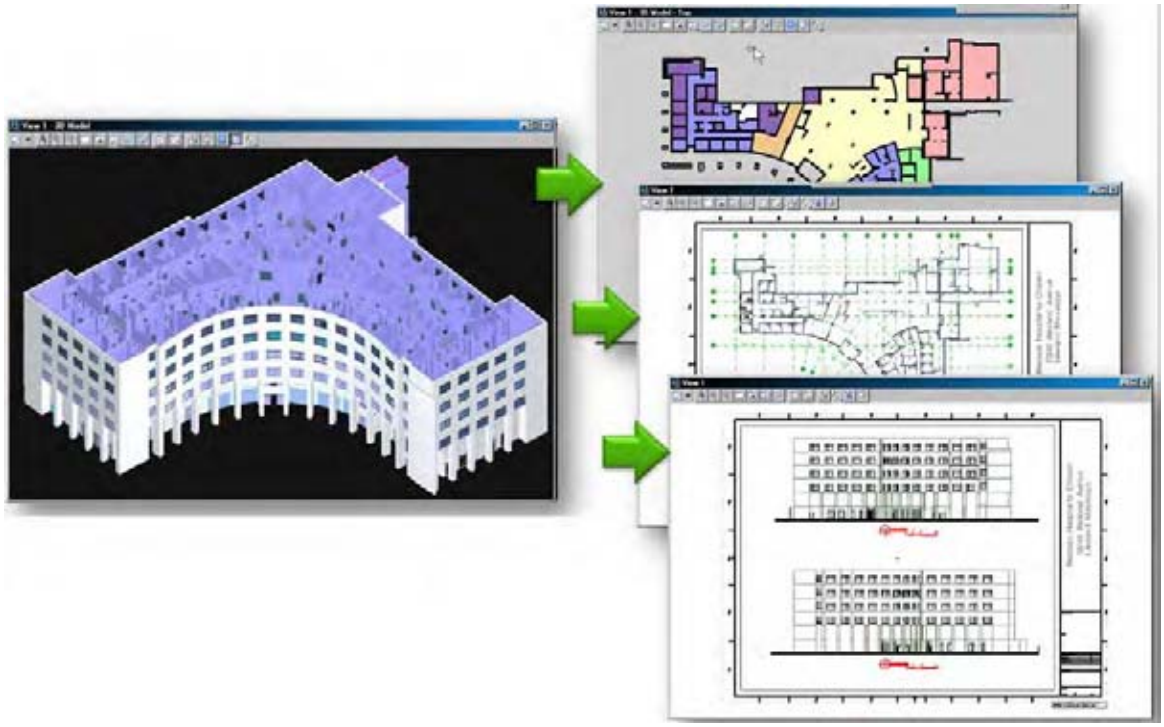


FIGURE 4. Drawings in Bentley Architecture are now dynamic and automatically update if the model is changed.

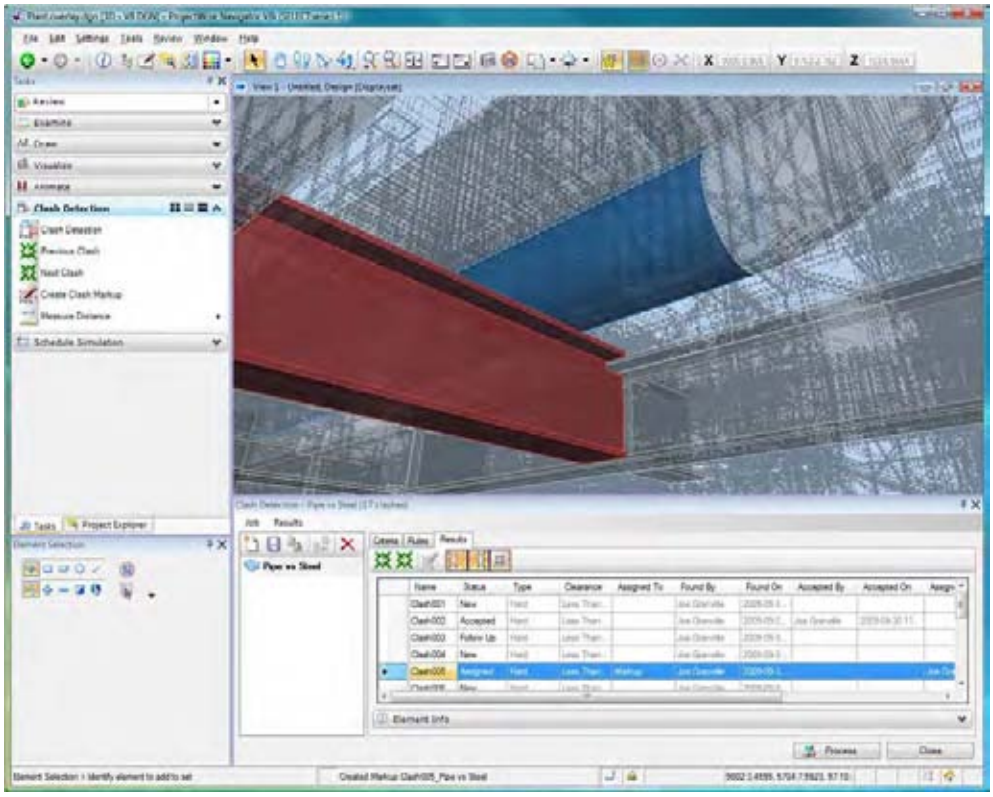


FIGURE 5. The use of Bentley's ProjectWise Navigator for multi-disciplinary coordination and review.

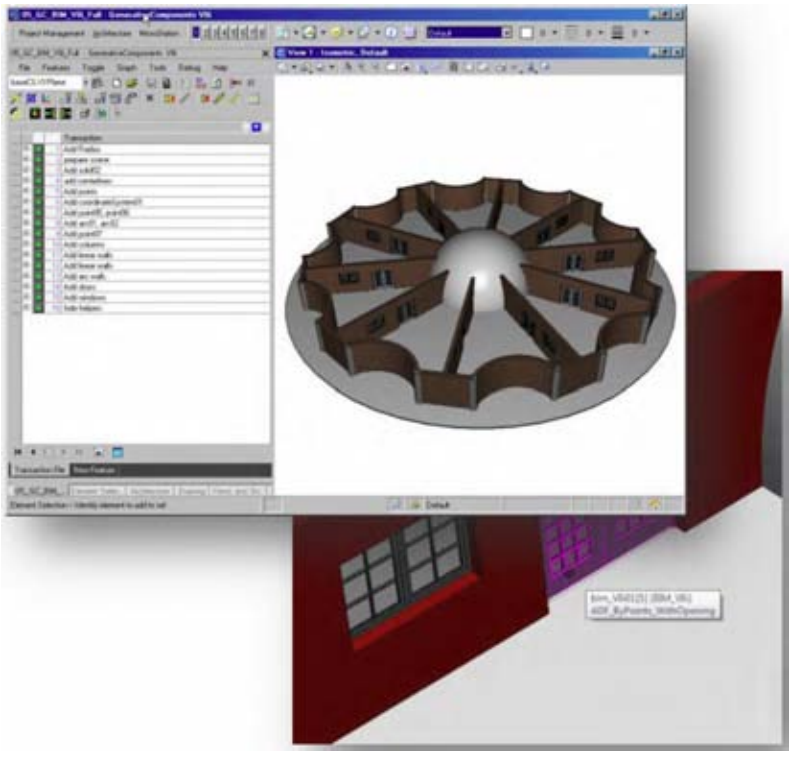


FIGURE 6. Using GenerativeComponents to locate a wall and automatically create openings in it at designated positions.

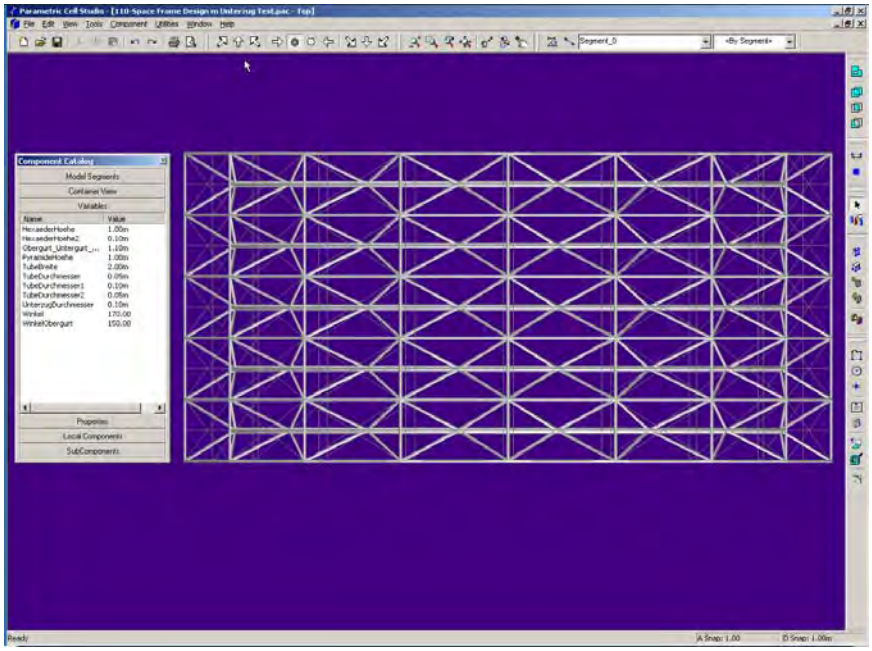


FIGURE 7. A space frame created using Bentley's Parametric Cell Studio.

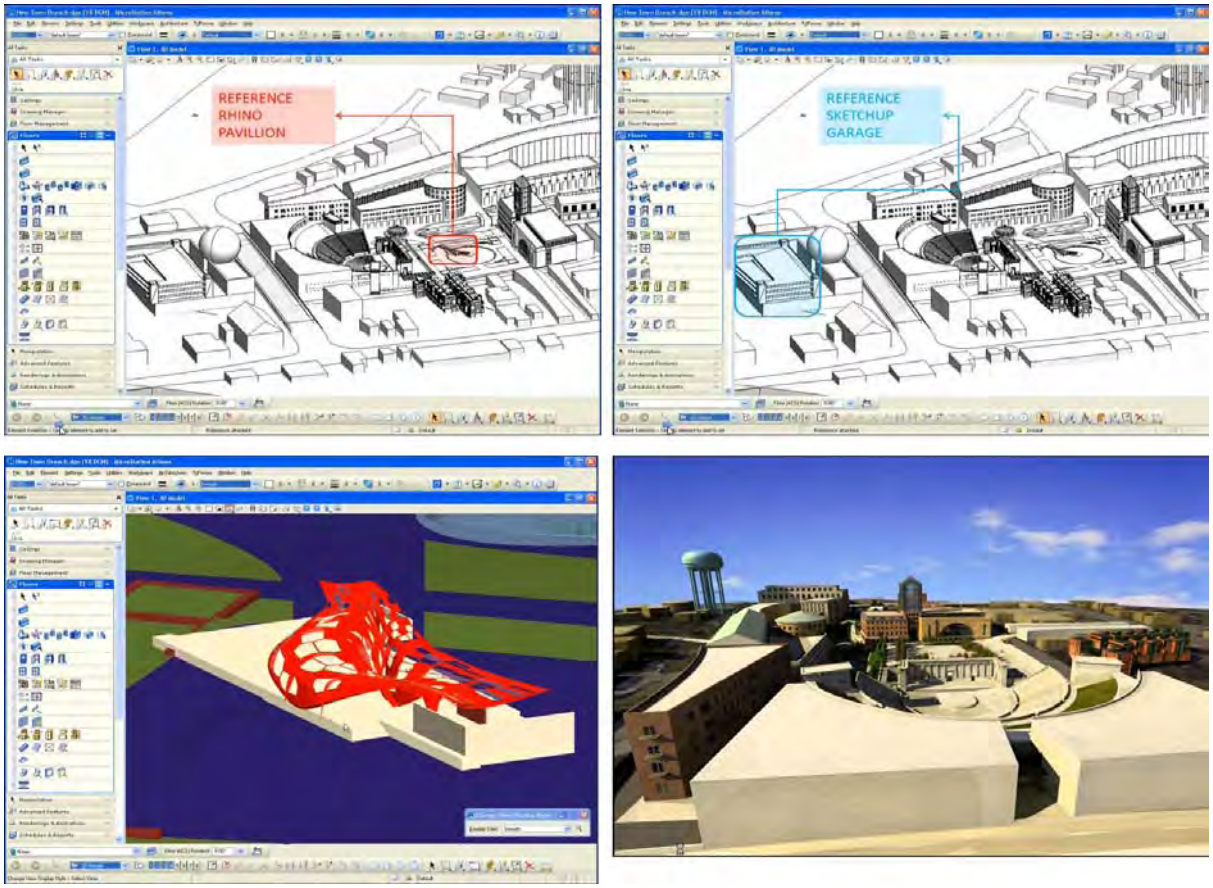


FIGURE 8. Rhino and SketchUp files directly referenced in a Bentley model. A close-up view of the Rhino model is shown, along with a rendered image of the entire project.

DISCUSSION

This section discusses some of the key features of Bentley Architecture in more detail.

Project Setup

Bentley has a federated database approach to BIM, where all the data related to the building is not centralized in a single building model contained in one file, but is instead distributed across multiple files. This makes its BIM solutions very different from applications like Revit and ArchiCAD that use the centralized building model approach, where much of the project organization and setup is already taken care of and you can go in and start modeling right away.

In contrast, in Bentley Architecture, you first have to think about how the project will be organized and create the necessary structure. There is no fixed way to do this. The entire model can be created in one file, which can also hold all the 2D drawings, views, sheets, and so on, similar to how separate worksheets can be created within the same Excel file. Alternately, separate files can be created for the models, drawings, sheets, images, other documents, and so on. The latter is the more common approach. Even for the building model, it can be entirely contained in one file, or it can be broken down into multiple models in different ways: by floor, interior elements versus exterior facade, and so on. Not only does the project structure have to be determined beforehand, care also has to be taken to follow it as the project progresses. Of course, once firms have determined a project structure that best suits their needs and workflow, they can standardize on it for all future projects and it would not be as time-consuming and difficult to implement every time.

In earlier releases of Bentley Architecture, the only way to organize a project was through the use of folders. There would be a folder for a project that would contain sub-folders for holding the models, drawings, and so on. This made it difficult to see the project structure and access the different files from within the application. This was a serious limitation that was finally overcome by a Project Explorer interface introduced a few years ago. This allows one or more "link sets" to be created, which can contain links to different project data such as model files, drawing files, sheet files, and other documents, categorized in folders as required. This allows the user to navigate more easily through all the different components of a project, without leaving the application (see Figure 9).

Any file can be opened from the Project Explorer by right-clicking on it. As the project progresses and new files get created, options are available to automatically create the links for these files in the Project Explorer. While the Project Explorer may look similar to Revit's Project Browser or ArchiCAD's Project Map, the critical difference is that the Project Explorer in Bentley Architecture is an optional component rather than an integral aspect of the application. It provides a more convenient way to access the project files, whereas in Revit and ArchiCAD, it is the only way to access the different views of the model.

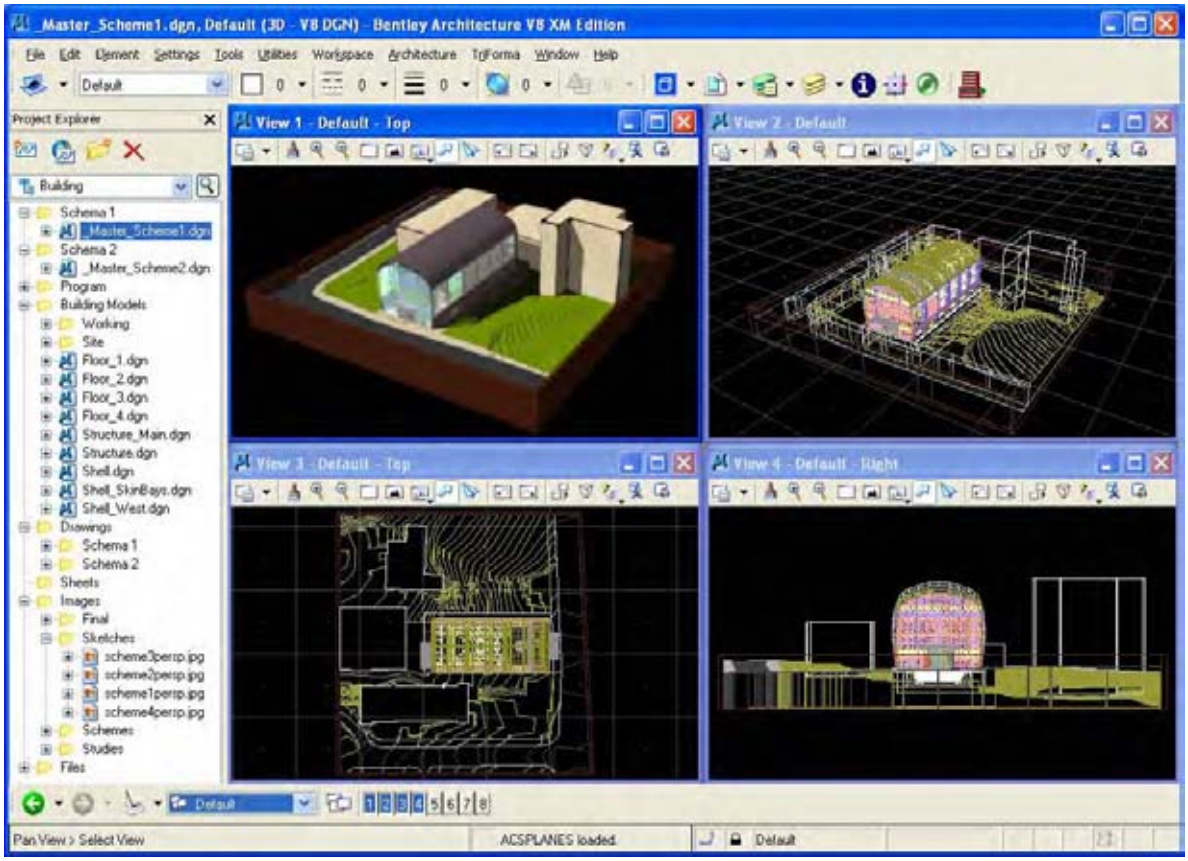


FIGURE 9. The Project Explorer interface of Bentley Architecture that was introduced a few years ago allows the different components of the project to be more easily accessed.

Bentley's federated, decentralized approach to BIM is not only more complex and less intuitive than the centralized building model approach, it also has a more serious limitation related to coordination and change management. Since the entire building is not contained in a single model, any change that affects the entire model cannot automatically ripple through all the affected components, which may be located in a file that is different from the one in which the change has originated. For example, changing the floor height of one level will not automatically adjust the elevations of all the upper floors if they are in different files. They have to be manually changed by the user, which could lead to coordination errors. It should be noted that other BIM applications which use the federated approach like Allplan and Digital Project have been able to find a solution to this problem, indicating that the problem is not endemic and Bentley is lagging behind in implementing a solution for it.

On the plus side, the federated approach is also what gives Bentley Architecture its main edge over competing single model-based applications—the ability to adapt more easily to distributed work processes and handle projects of any complexity. The different files making up a project can be easily handled by several project members working simultaneously, and since the master model can reference an unlimited number of smaller models, which in turn can have any number of attached references of their own, Bentley's BIM solutions are able to model very large or complex projects just as easily as smaller ones. There is also the flexibility of creating different "master models" that assemble together different model files to view different aspects of a project if required.

Interface

All the Bentley applications include what is known as the "task based" interface, which allows the vast array of tools and commands in each application to be organized according to tasks. For example, in Bentley Architecture, all the tools relevant to the modeling of floor plans such as those creating walls, doors, windows, stairs, and so on can be grouped in one category, while tools relevant to the modeling of the site can be grouped into another category. There are also different task interfaces to cater to different needs and levels of expertise; for example, Architecture, Advanced Architecture, New User, etc. While the task-based interface may seem just like the tool palettes of other BIM applications that also have different tools organized in related categories, the difference is that the task-based interfaces in Bentley Architecture are fully customizable by the user. In fact, shortly after Revit Architecture 2010 was released with its ribbon interface that caused a lot of discontent among its users, Bentley released a task-based interface that was identical to that of Revit Architecture 2009 (see Figure 10), in an effort to make a point about the flexibility of its interface.

Also, Bentley's task-based interface makes a reference to a specific tool rather than physically placing in a designated tool palette, which means that the same tool can appear in multiple palettes if required. Users can also create their own task-based collections for various tasks at different design stages, which can be used individually or across a firm to standardize core processes and improve efficiency.

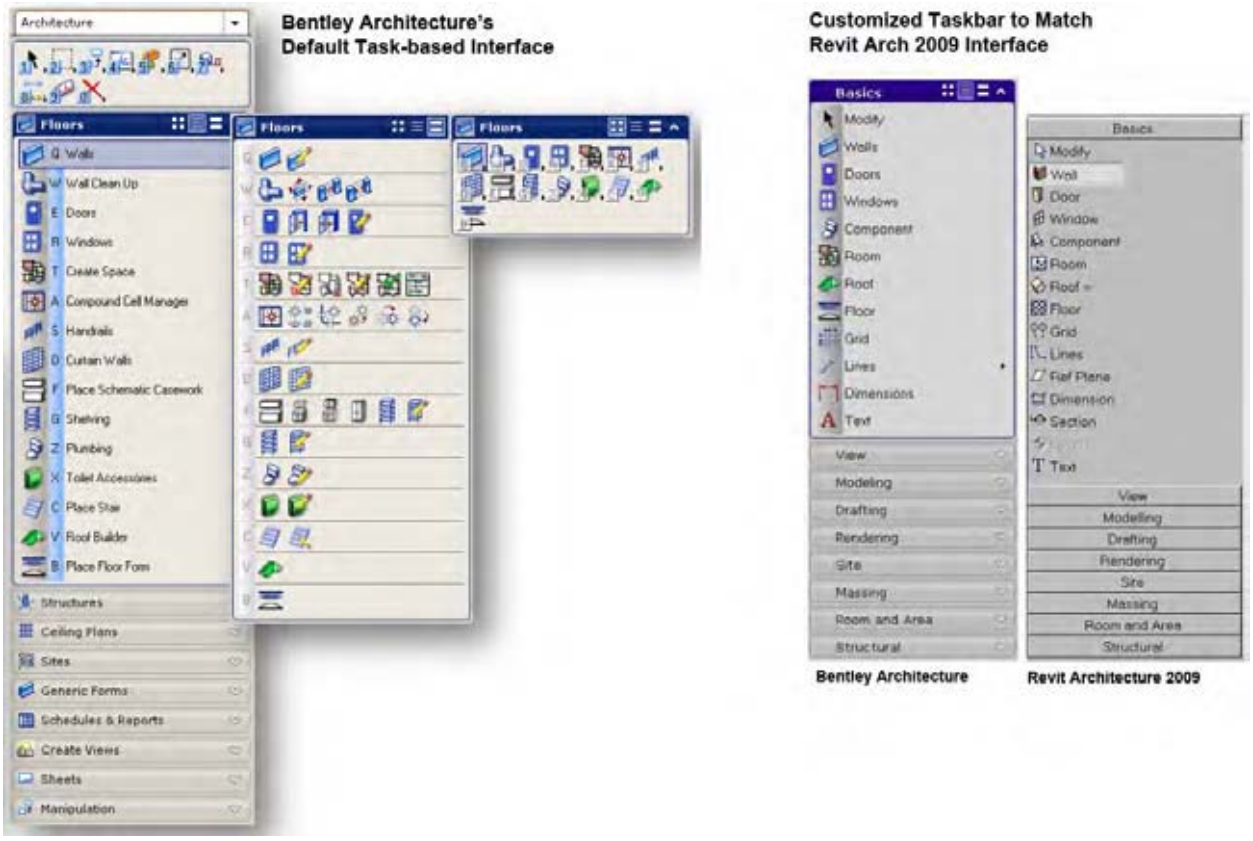


FIGURE 10. Bentley's task-based interface, shown on the right, which mimics that of Revit Architecture 2009, which has been replaced by a ribbon-based interface in Revit Architecture 2010. The default Bentley interface is shown on the left.

Another noteworthy feature of Bentley Architecture is the MicroStation-based AccuDraw drawing aid as well as excellent snapping capabilities that allow the modeling to be as precise and accurate as required. Bentley Architecture also recently introduced a limited form of the heads-up display that Revit has had from the beginning. In Bentley Architecture, the heads-up display is not available when creating elements; it activates only when you select an element that has already been created, as shown in Figure 11. For accurate modeling, you still have to rely on AccuDraw, which also works very well but is not as graphically intuitive as Revit's heads-up dimension display. Also, Bentley's heads-up display works only with some elements such as walls, columns, beams, and so on. You cannot, for instance, use it to reposition a door or a window on a wall more accurately, as it doesn't work for these elements.

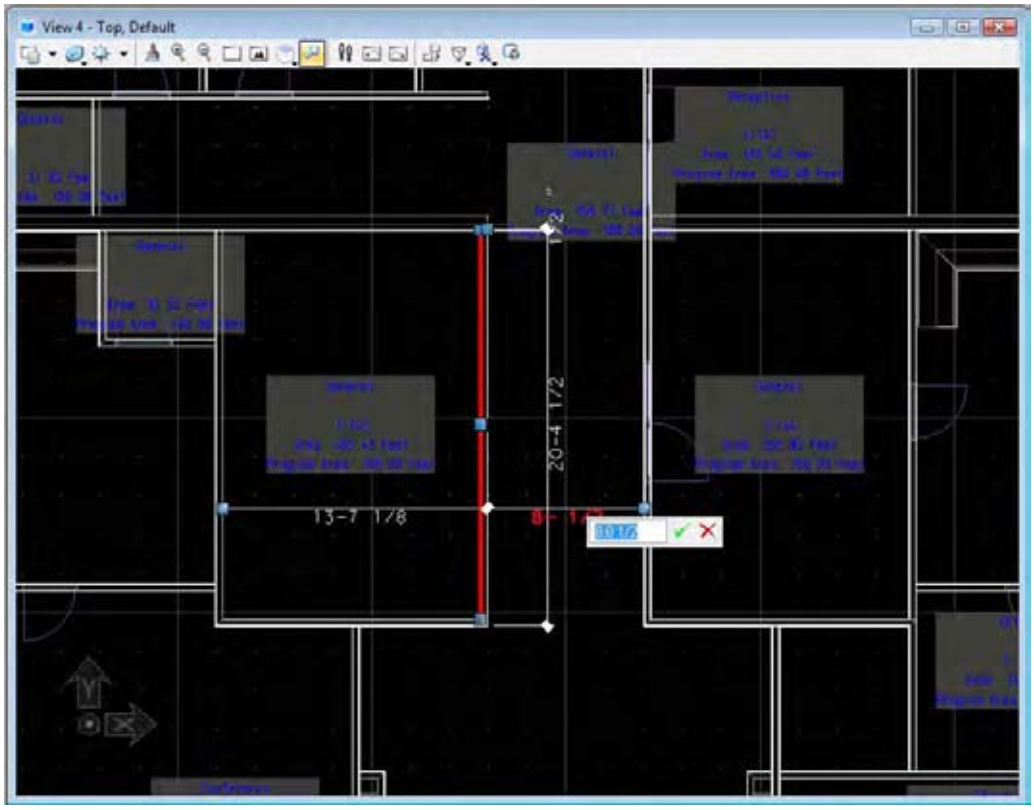


FIGURE 11. The heads-up display available for editing in Bentley Architecture when an element such as a wall is selected.

Functionality

Since Bentley Architecture is built on top of MicroStation, a very powerful and comprehensive CAD application, it inherits all of its many capabilities: a full range of surface and solid modeling tools; powerful visualization and animation capabilities powered by the Luxology rendering engine with full-blown radiosity, which can create highly photorealistic renderings and animations; a vast array of dimensioning and annotation tools for creating drawings and details; a Design History capability, which can track changes to models and restore a model, if desired, to a prior state; the ability to work directly with DWG/DXF files; support for several database formats allowing data to be imported as well as exported; and the ability for users and third party vendors to extend and customize the applications using APIs.

In terms of functionality specifically for architectural design, Bentley Architecture leads both Revit Architecture and ArchiCAD by having some built-in space planning tools and SketchUp-like conceptual modeling capabilities, with a Push/Pull feature and the ability to divide a face by simply drawing on it. While not as intuitive to use as SketchUp, Bentley Architecture goes further by enabling true curved and double curved surfaces and solids, which you cannot create accurately in SketchUp. Some examples of conceptual models created in Bentley Architecture are shown in Figure 12. Bentley Architecture, however, lacks the capability to automatically derive the building shell—with intelligent wall, floor, and roof "BIM" objects—from a schematic massing model, which Revit Architecture includes in its BuildingMaker functionality. So the effort spent in developing a massing model cannot be effectively directed towards jumpstarting the detailed design process, as you can in Revit.

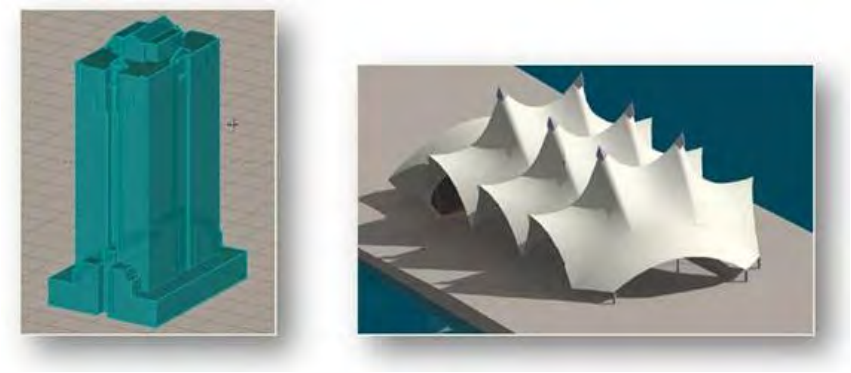


FIGURE 12. Conceptual models created in Bentley Architecture.

Another useful schematic design option in Bentley Architecture is the ability to create conceptual block models of buildings and cities, derive the schematic plans and sections, and generate an early cost estimate based on the space utilization (price per sq.ft. or cu.ft), as shown in Figure 13.

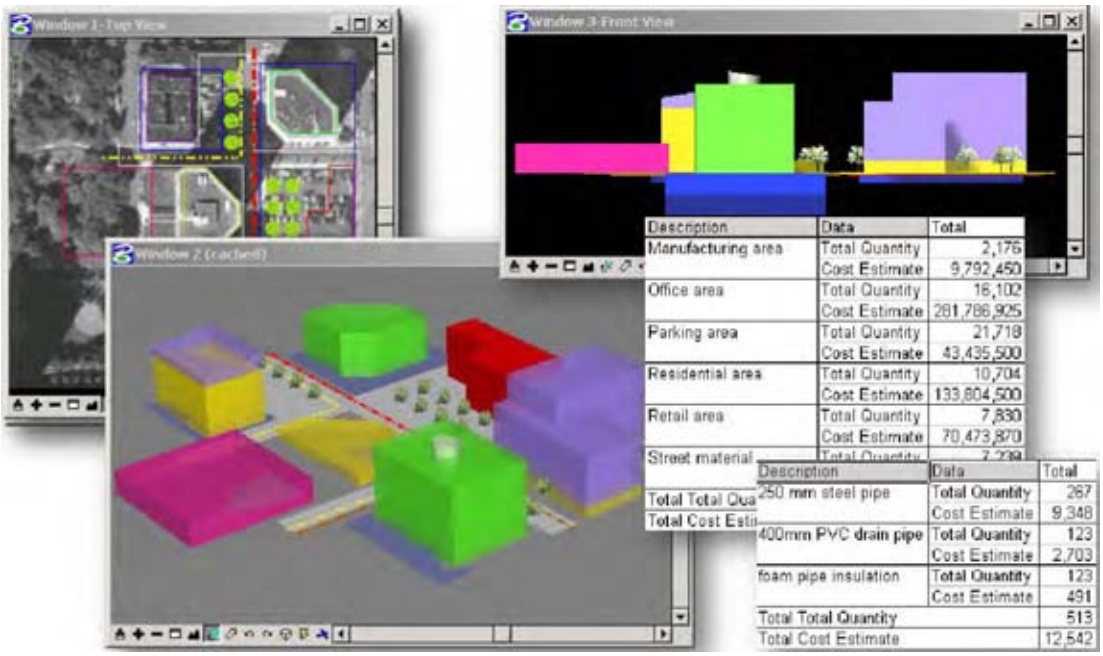


FIGURE 13. Conceptual design building and city block modeling with early stage cost estimates.

Bentley Architecture is also very strong in detailed design. It has an extended toolset for modeling the site as well as different building components such as walls, curtain walls, doors, windows, columns, ceilings, floors, stairs, and so on. The Walls toolset, for instance, comprises several tools for different functions: placing walls, and placing and building wall assemblies; breaking, joining, and connecting walls; modifying wall geometry and wall type; cleaning up wall intersections and managing automatic wall unification in the 2D drawing generated from the model; making cuts in walls; and, creating wall pockets and recessed utility areas to accommodate other building design elements.

When any building element is created, default settings are used for its type information, which can be changed later when required. This allows the designer to focus on the design and its modeling without being burdened by specifying type information until necessary. Type specifications follow industry standards, with higher-level categories called *families* containing several individual element types called *parts*.

For the modeling of non-regular building geometry, Bentley Architecture lacks the ease with which, for example, walls, beams, and columns can be slanted, curved in elevation, or given a custom cross-sectional profile in ArchiCAD. You can, however, create any kind of complex geometry using the MicroStation surface and solid modeling tools, and then add BIM information to it. This will not make the object behave like a BIM object; so, for instance, a complex wall created using the geometrical 3D tools rather than the Wall tool will not automatically cut openings when doors and windows are placed in it. However, it will be recorded in the schedules and in quantity take-offs as a wall object. Spaces placed inside complex wall shapes do not automatically take on their geometry as they do in ArchiCAD, but remain vertical extrusions of the space footprint; this can be a limiting factor in analysis applications like energy and in HVAC design that need accurate volume calculations of spaces.

Bentley Architecture also includes additional utilities such as the DataGroup System, which is used to manage building objects, add custom attributes to them if required, and generate schedules and other needed reports; a Quantity Takeoff tool that can extract needed information from a 3D model and export it in the form of spreadsheets or databases; and the Parametric Cell Studio, a standalone application for the creation of parametric objects such as doors, windows, casework, curtain walls, stairs, trusses, etc.

For more complex parametric design, the recent integration of GenerativeComponents with MicroStation has made its capabilities a lot more accessible to users of Bentley Architecture. It allows generative design to be used to create forms based on function in many standard projects rather than in just the "signature architecture" that is typically associated with the use of GenerativeComponents. As shown in Figure 14, GenerativeComponents provides new ways to efficiently explore alternative building forms without manually building the detailed design model for each scenario, and it can be used effectively on overall building forms as well as smaller details. It includes a BIM Features add-on that can be used to specifically create architectural content for use in Bentley Architecture.

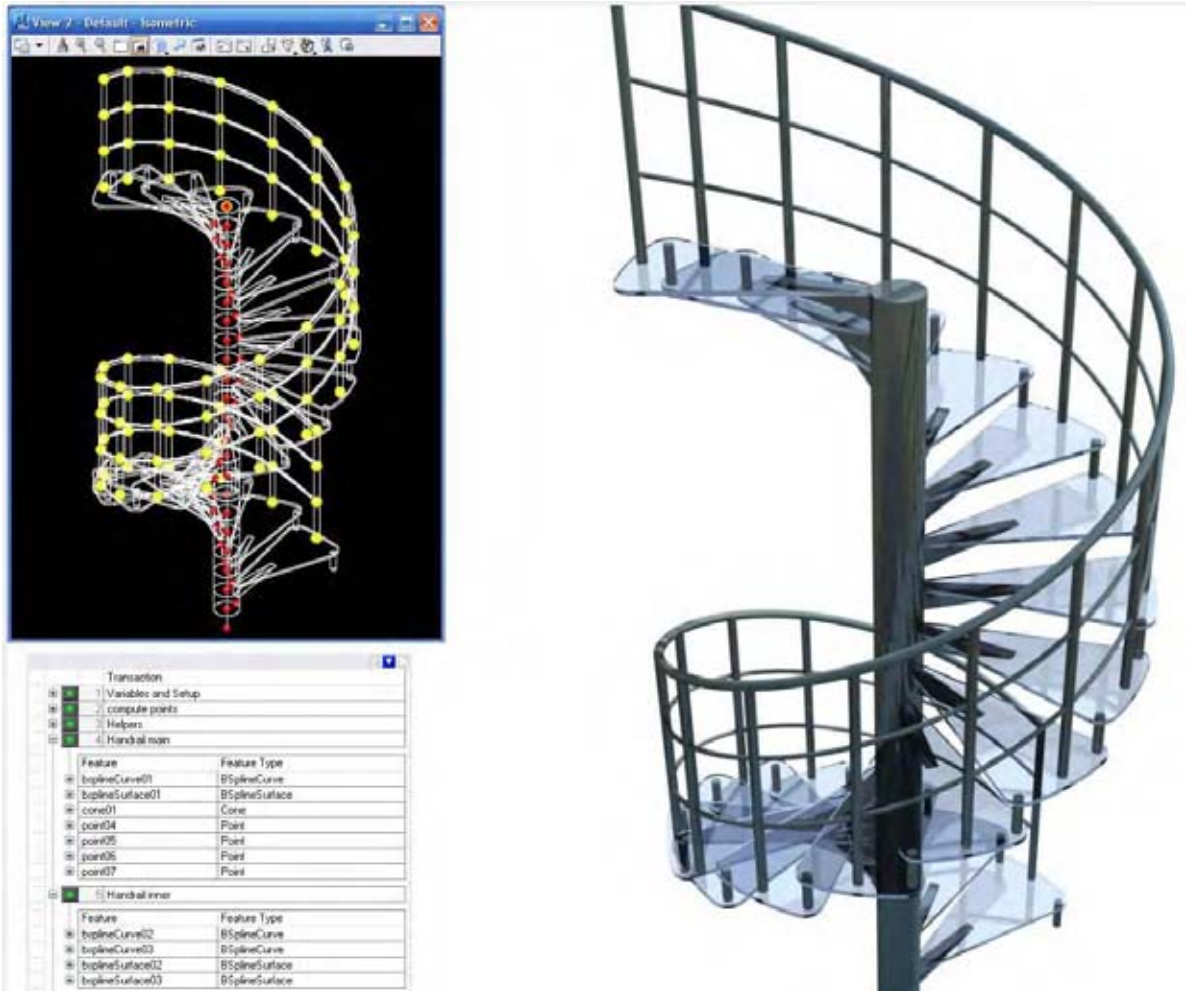


FIGURE 14. Creating a fully parametric BIM stair object for a Bentley Architecture project using GenerativeComponents.

Up until the last major release, drawings in Bentley Architecture were section cuts that had to be extracted from the model using a Drawing Extraction Manager utility, with different "drawing definitions" specified for different types of drawings such as floor plans, sections, etc., to determine how they would be displayed. The extracted drawing maintained a link to the model, but was not live; therefore, if the model was changed, the drawing wasn't updated automatically, but it would be recognized as being out-of-date when opened, giving the user the choice of updating it. In the latest V8i version of Bentley Architecture, the process of creating drawings from the model was significantly overhauled with a technology labeled "dynamic views," with drawings becoming live views of the model that are automatically updated when the model is changed. This has been a significant step in bringing Bentley Architecture up to speed with its main competitors: in Revit Architecture, drawings have always been live views of the model and synchronized with it, while in ArchiCAD, drawings can be set to update either automatically or manually. These drawing views in Bentley Architecture can be generated not only from the model but also from other drawing views, as shown in Figure 15, which is very convenient. Also, since Bentley Architecture can maintain "live" links to other file formats such as DWG, 3DS, OBJ, Sketchup, and Rhino, it is able to automatically update the drawings based on changes to those files as well. This is a capability that none of the other BIM applications have.

FIGURE 15. Creating a section from a plan view in Bentley Architecture and placing it on the same sheet.

Another aspect of the dynamic views technology that is quite remarkable is the ability to position planes in different angles to explore sectional views, as shown in Figure 16, and apply a wide variety of display styles to the forward, cut, and back portions of the sectioned model. This provides the ability to create extremely rich visuals of plans, sections, elevations, and 3D sections. A few examples are shown in Figure 17. Each dynamic view can be stored with its own drawing rules, which will determine not only the overall display styles but also the display of individual elements such as walls, columns, spaces, stairs, etc.

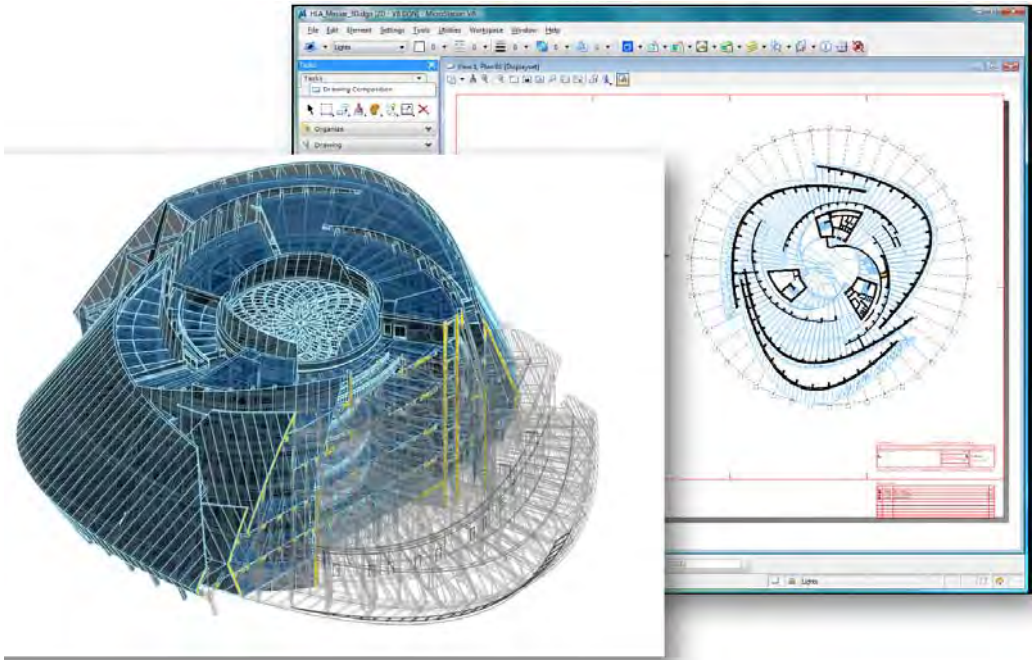


FIGURE 16. A complex sectional 3D view made possible by the new display enhancements in Bentley Architecture.

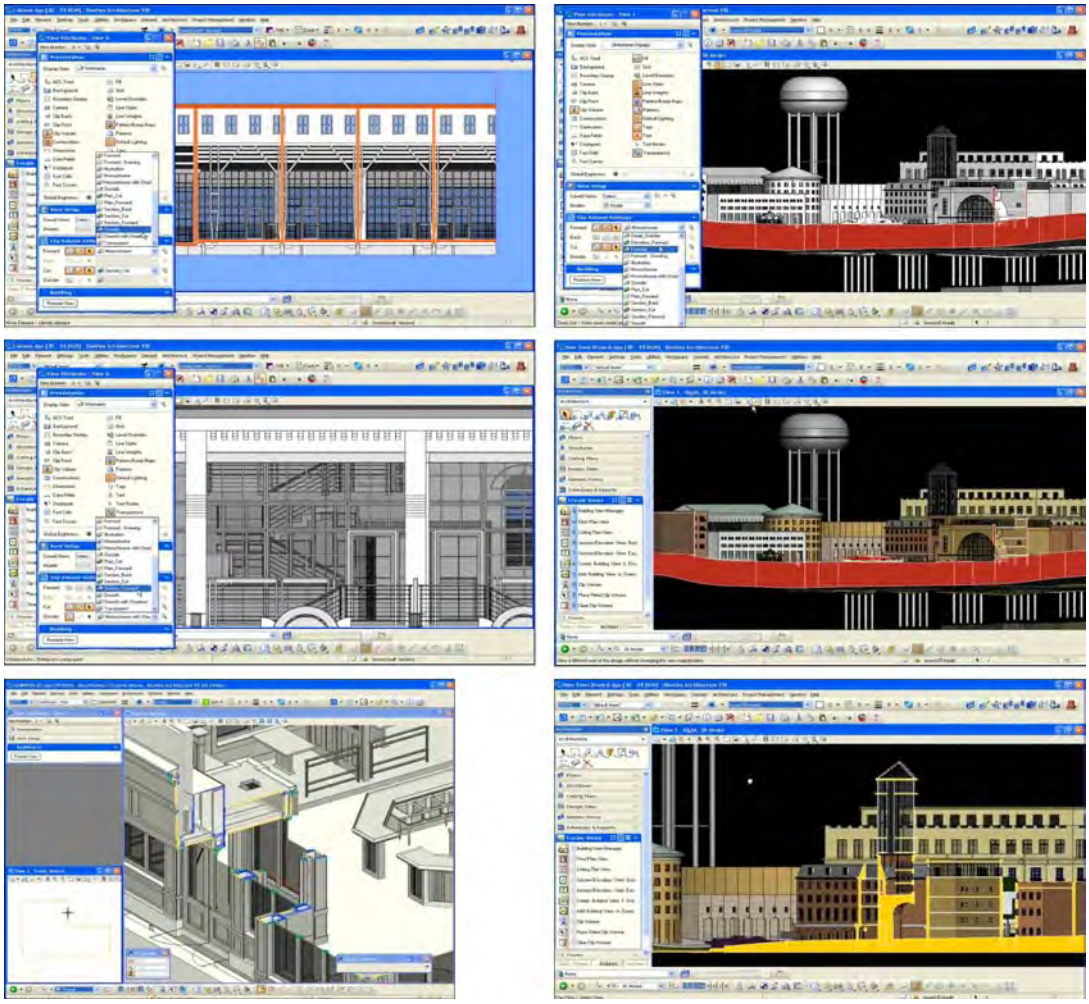


FIGURE 17. The wide range of display styles that can be applied to create visually arresting presentation graphics of designs in Bentley Architecture.

The flip side to Bentley's new dynamic views capabilities is that it adds an additional layer of complexity to Bentley's already very complex interface. The drawings, which would typically be created from a master 3D design model referencing a number of individual 3D design models (as mentioned in the section on Project Setup) have to be stored in a separate 2D "container" called the "drawing model." From here, they can be dragged and dropped into "sheet models" which are designed to hold the individual pages of the document set for the project. It can be quite confusing to figure out and navigate through all these different constructs. While the Project Explorer does make it easier to manage all the different models, drawings, views, and sheets, the process of actually creating all of these different project components is still much more complex in Bentley Architecture compared to other BIM applications.

CONCLUSION

Bentley Architecture has many impressive capabilities. To start with, it is part of a large and comprehensive array of Bentley solutions that cover most of the tasks in AEC including site design, multi-disciplinary building design and engineering, structural analysis and detailing, building performance analysis, collaboration and project

management, interference checking and design coordination, construction simulation, and facilities management. By virtue of being built on top of MicroStation, it inherits a solid and extensive repertoire of CAD and 3D modeling capabilities that have been honed over years of development. With the ability to create any kind of complex geometry using surface and solid modeling tools and then add BIM information to it, there are relatively few constraints on the building form the application can handle. Another significant benefit to Bentley users is the availability of the ProjectWise platform for project and file management, particularly for large distributed project teams. Bentley's federated approach to BIM, where the project data is distributed across multiple files rather than contained in one file, and its constantly improving capability to work with multiple file formats, enables it to be more easily used by distributed project teams and applied to large building projects just as readily as to small ones. Other key strengths include the closer integration of GenerativeComponents with the Bentley BIM applications, helping to make its parametric design capabilities more accessible to Bentley users.

The federated approach however, comes with its own set of limitations, making project setup a lot less automated and a lot more complicated. The project team needs to put in a lot of work determining how the project is going to be divided into files, set up the project structure accordingly, and take care to maintain it as the individual team members create the different files that will make up the model. There is no option to even define the levels of the building and have the application automatically create the corresponding files for the different floors, as there is in all the other BIM applications. There is no automatic change management across files, so any changes to associated elements in different files have to be made manually. Also, there is no real-time collaboration, since all the team members are simply working on different files rather than on one model.

The other main issue with Bentley Architecture is its complexity. There is a plethora of tools to work with, and the interface is not very intuitive. Also, mastering Bentley Architecture requires learning MicroStation as well, which means that users will essentially have to master two complex applications, not just one. Even the documentation is not self-contained—for help with any of the base platform functionality, users will have to refer to the MicroStation documentation. The difficulty in learning is compounded by the poor quality of the accompanying documentation, especially that of Bentley Architecture. It fails to provide a good explanation of how to even set up a project. For new users, especially those who are already familiar with more user-friendly BIM applications such as Revit Architecture and ArchiCAD, Bentley Architecture can be completely bewildering. Better documentation is badly needed, along with some re-tooling to make the interface more intuitive, consolidate functions, and remove out-dated tools.

Bentley's growing reach into other infrastructure disciplines is highly admirable and adds to the company's overall strength and bottom line; at the same time, it does lead to the question of whether this translates to a diminished focus on its Building solutions. At the current time, Bentley lists 13 infrastructure disciplines that it provides solutions for, of which only two fall in the domain of traditional AEC firms: Buildings and Campuses. Thus, the question of diminished focus is a legitimate concern. Of course, the Building solutions will continue to benefit from the improvements that are continuously made to the base MicroStation platform, and Bentley's increasing success in other disciplines will help to ensure its long-term viability and availability of development resources. But unless the company shows some serious innovations to its building solutions that will improve project setup, collaboration, and overall usability, there's a chance that it will get increasingly overshadowed by the other BIM applications, especially among architectural firms.

ArchiCAD

ArchiCAD made its debut in 1987, making it one of the earliest design applications in the AEC industry. It was also one of the first applications to incorporate the idea of object-based modeling, where a design is represented not just with graphical entities, but with geometry to which building element attributes are attached. Thus, it can lay claim to being one of the first applications with BIM-like capabilities, long before the term BIM was even introduced by Autodesk after its Revit acquisition in 2003. In fact, one of the most iconic projects first associated with the use of the BIM is an ArchiCAD project—the Eureka Tower in Melbourne, Australia, which was completed in 2006. The actual building is shown in Figure 1, along with a rendered image created using ArchiCAD. The project was designed by Fender Katsalidis Architects, an Australian architectural firm which, to date, remains one of the key users of the application.

FIGURE 1. The Eureka Tower in Melbourne, Australia, one of the largest and earliest projects created using any kind of BIM technology. Both the completed building and an ArchiCAD generated rendering are shown on the left and right, respectively.

ArchiCAD is developed by Graphisoft, which is headquartered in Hungary but has a well-established presence in many parts of the world, including the United States. Graphisoft was acquired by the Germany-based Nemetschek AG in early 2007. This has provided the company with financial stability in the increasingly difficult economic times that have followed. At the same time, by remaining an independent unit within Nemetschek, Graphisoft can continue with the development of ArchiCAD as per the vision of its technology and executive teams, which still include many of the original founders and developers of the application.

Prior to its acquisition, the company was headed for several years by Dominic Gallello, a seasoned industry executive whose prior experience included a long stint at Autodesk. Under his leadership, Graphisoft pioneered the idea of developing "virtual construction" (another name for BIM) solutions for contractors in 2004, which were then spun off into a separate company, VICO Software. Graphisoft's current CEO, Viktor Varkonyi, has been with the company for several years and has an indepth understanding of its technology. The strong, technologically savvy leadership has resulted in several noteworthy innovations in ArchiCAD over the recent years, including easier modeling of complex forms, interactive training guides that run within the application, a sophisticated Virtual Trace feature that simulates the physical tracing paper concept, the ability to create 3D documentation to supplement traditional 2D documentation, a built-in energy analysis add-on tool called EcoDesigner, support for both multi-processing and 64-bit computing, and many more. This groundswell of innovation has far from abated and produced a revolutionary new server-based collaboration and worksharing capability in the recent release, ArchiCAD 13, which allows distributed project teams to collaborate on a model more easily and efficiently.

EVALUATION SUMMARY

Key Strengths

- Mature application with a long history of object-oriented (BIM) modeling
- Includes the ability to easily model inclined walls, beams, and columns, or apply custom profiles to them, without losing the benefits of BIM
- First of its kind BIM-server based collaboration capability that supports distributed project workflows and real-time collaboration
- Only BIM application currently available that supports both multi-processing and 64-bit support, making it noticeably faster and allowing users with the latest hardware to make maximum use of its capabilities
- Provides ease of use of centralized model, but has a more efficient file structure, with smaller file sizes compared to Revit
- Many in-house and third-party add-ons, including EcoDesigner for energy analysis and an MEP Modeler
- Excellent documentation capability, including the ability to create 3D documents with annotation and dimensions applied to 3D views
- Excellent quality of learning resources, including many Interactive Training Guides
- Very nimble and technology-oriented company, with technically savvy leadership
- Continuous run of impressive innovations in the last several releases
- Very responsive to customer requests
- Cross-platform (Windows and Mac)

Main Limitations

- Is a stand-alone architectural BIM application rather than part of a multi-disciplinary suite of building design applications
- Lacks Revit's intuitiveness and ease of use
- Missing any space planning, conceptual design, or massing capabilities
- Lacks a full set of solid and surface modeling tools for freeform modeling that is available in some of the other BIM applications
- No automatic object intelligence (associative behavior), which increases the number of modeling and editing steps required to develop a model
- No modeling constraints of any kind, which does not guarantee the integrity of the model for downstream analysis applications that need to work with it
- Uses "zone" elements instead of the "space" elements commonly used in other BIM and AEC applications
- Individual licenses need a USB hardware key to run, which is quite inconvenient
- Has not been a very aggressive competitor to Autodesk in the US, despite having a strong technology

Price

- $4,250 for a new license
- $895 for upgrade
- Free educational version for students

DETAILED EVALUATION

Application Repertoire

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Space Planning/ Programming			✓	No built-in tools for programming and space planning; a plug-in allows bidirectional integration with Trelligence Affinity, a sophisticated third-party space planning application. Also lacks a dedicated "Space" tool, using a "Zone" tool instead.
Conceptual Design/ Mass Modeling			✓	No built-in tools for conceptual modeling; a plug-in is available to translate 3D conceptual design geometry developed in SketchUp to the appropriate building objects in ArchiCAD.
Detailed Modeling	✓			Includes a comprehensive toolset for creating walls, columns, beams, roofs, slabs, meshes, zones, stairs, and curtain walls that is on par with other BIM applications.
Schedules and Reporting	✓			Schedules are bi-directionally linked to the model, and can contain preview pictures (*see Figure 2*). In addition to schedules for building elements, there is the ability to define and place various project indexes such as a drawing list, view list, or sheet index.

Quantity Take-off	✓			Includes the ability to generate component lists as part of its scheduling capabilities, which sum up and display component type properties and are used for bills of materials and quantity takeoffs. In addition, quantity information can be exported through ODBC drivers to external estimating applications.
Photorealistic Renderings	✓			Good photorealistic renderings can be generated within the application using the built-in Lightworks rendering engine (*see Figure 3*). There is also bi-directional integration with Artlantis, a popular rendering application.
Animations		✓		Includes the ability to create fly-through animations, animated sun studies, as well as navigable VR (virtual reality) movies of objects or scenes. However, there is no dedicated set of animation tools such as keyframes, timeline and velocity graphs, etc. like Bentley Architecture.
Real-time Model Exploration	✓			Includes a 3D Explore mode that allows easy game-like navigation and exploration of the model in a perspective view. Model can also be exported to the Virtual Building Explorer add-on which allows the model to be explored with real-time 3D navigation enhanced with stereo viewing modes, gravity, layer control, fly-mode, egress recognition and pre-saved walkthroughs, and includes query and measurement tools.
Construction Documents	✓			Has a full set of tools for producing construction documents, with many advanced features such as automatic exterior and interior dimensioning, the ability to produce 3D documentation, worksheets that are optimized for creating partial floor plans and partial sections, the ability to quickly create a set of interior elevations, and a wide variety of displays styles and fill types for creating high-quality presentation drawings.
Coordination/ Clash detection		✓		This capability is only available as part of the MEP Modeler add-on to detect conflicts between the architectural design and the MEP network.
Fabrication			✓	No special capability beyond the ability to export detailed geometry information in ODBC format. No native support for STL or STEP formats commonly used for fabrication.

Intrinsic Nature and Capabilities

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Intuitiveness and Ease of Use		✓		The interface has been redesigned in recent releases to improved usability, with less clutter, a Tracker input feature for precise modeling, and excellent model navigation tools. But it is still quite complex to master compared with Revit. Dialog boxes are overloaded with graphic and textual information, which makes them quite overwhelming. There is no option to tile open windows.
Ease of Project Setup	✓			Setup is a little more involved compared to Revit, but is still largely automated and much easier compared to the other BIM applications.

Information Re-Use			✓	There are no conceptual design or space planning capabilities, so there is no scope for re-use of this information for detailed design.
Modeling of Organic Building Forms		✓		Walls, beams, and columns can be easily slanted or inclined, and custom cross-sectional profiles can be used to create more complex elements, which still retain their BIM nature. A Mesh tool, developed primarily for site modeling, can be used for some freeform modeling, and more freeform modeling capabilities are provided by a third-party plug-in tool called ArchiForma. However, it lacks a full set of solid and surface modeling tools needed for creating complex organic forms that are available in some of the other BIM applications.
Automation of Tasks		✓		Add-ons such as RoofMaker, TrussMaker, and ArchiGlazing are available for automating some tasks. In addition, there are automatic exterior and interior dimensioning capabilities.
Creation of Parametric Forms			✓	Parametric BIM objects can be created with GDL to use in ArchiCAD. But there is no sophisticated parametric modeling capability of the kind provided by Digital Project or Bentley's GenerativeComponents.
Associative Behavior of Building Elements			✓	Building elements do not automatically maintain relationships with related elements when moved or otherwise modified. This diminishes the fluidity and ease of use of the application.
Guarantee of Model Integrity			✓	Does not disallow any illegal operations: walls can intersect with other elements, doors and windows can be moved out of walls, doors and windows can overlap with each other on the same wall, and so on. So the integrity of the model becomes the onus of the user and is not guaranteed by the application.
Availability of BIM Content		✓		Ships with over 1000 parametric GDL objects. Various manufacturer libraries are available in different countries including doors and windows, MEP fixtures and over 40,000 internationally standard steel profiles for structural elements. Advanced users can write GDL scripts for creating custom parametric objects. Generic 3D content in popular formats such as DWG can be imported from content portals such as the Google 3D Warehouse. However, the number of third party developers creating ArchiCAD-specific content is relatively limited.
Customization Capability	✓			The ArchiCAD workspace is fully customizable and individual users can save their desired settings in user profiles, which they can recall when needed.
Support for 3D Printing		✓		3D printing is only supported through the VRML file format rather than through the more common STL format.
Multi-Processing Support	✓			Supports multi-processing.
64-bit OS Support	✓			Available in a 64-bit version.
Cross-Platform (Windows, Mac)	✓			Runs on Windows XP, Windows Vista, and Mac OS.

Issues Specific to Large Firms

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Model Performance		✓		Although the model and all associated drawings are centralized in one file, a more efficient data structure and the use of GDL for object representation keeps file sizes reasonable.
Model Sharing Technology	✓			Includes a TeamWork module, which allows the building model to be divided into parts for different design teams to work on. It works with a model server that only sends modified elements back and forth between the master model and the local copies.
Support for Distributed Workflow	✓			A flexible reservation system allows model elements to be reserved and released on the fly, allowing for a dynamic workflow between a distributed team. Users can see who else is working on the project and the parts that they are working on.
Security and Access Controls	✓			The server-side component of the Teamwork module allows the project administrator to have full control over model access and the roles and responsibilities of team members. The roles can be customized in detail to control what parts of a project a given user is allowed to work with.
Performance Across WAN	✓			Since only the modified elements are sent back and forth between the master model on the server and the local copies instead of the whole model, working remotely on a collaborative project is not very bandwidth-intensive. A standard broadband Internet connection is sufficient.
Ability to Handle Large Projects		✓		Repetitive units can be handled using hotlinked modules, which helps to reduce the file size. Also, the multi-processing and 64-bit support make it easier to work with large projects. But since the model is centralized, file sizes do tend to get large.

Interoperability

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Integration with Structural BIM Applications			✓	No direct integration with established structural BIM applications; relies on IFC for collaborative, multi-disciplinary work.
Integration with MEP BIM Applications		✓		No direct integration with established MEP BIM applications. However, an extension called MEP Modeler is available which can be used to create, edit or import 3D MEP networks. A plug-in is available that allows direct import of MEP designs created in AutoCAD MEP.
Integration with Sustainable Design Tools	✓			Includes direct integration with Graphisoft EcoDesigner, which can be launched from within the application. Integrates with several other energy applications including Strusoft VIP-Energy, ArchiPhysic, Ecotect, GBS, IES, Riuska, and EnergyPlus using the API as well as gbMXL and IFC.
Integration with Estimating Applications	✓			Includes direct integration with VICO's estimating solution. Also integrates with international estimating solutions such as Arriba in Germany or Presto in Spain.
Integration with Constructability Tools		✓		Integrates with VICO's construction solutions.
Electronic Publishing and Review	✓			Includes built-in support for publishing 2D PDF files without the need for a driver, and supports the U3D file format, which can be converted into 3D PDF. Includes DWF-based own web publishing environment with Project Markup functionality, and integrates with Virtual Building Explorer for 3D interactive model publishing.
Range and Quality of Third-Party Tools	✓			A large number of third-party add tools are available: Artlantis for rendering, Trelligence for space planning and programming, ArchiFM for facilities management, FrameWright for timber framing, ArchiWall for freeform walls, ArchiForma for freeform modeling, ArchiTerra for terrain modeling, ArchiTime for time management statistics, ArchiCAD Master Template for organizing office standards, and many more.
Number of 3D File Formats Natively Supported		✓		Supports common file formats such as DWG, DXF, DGN, IFC, OBJ, 3DS, and VRML, but not STL, STEP, IGES, and others.
Quality of API	✓			Includes a full-fledged API (Application Programming Interface), which allows the application to be customized and add-ons to be developed for expanding its capabilities.
IFC Support	✓			Strong proponent of the IFC standard. Relies heavily on the IFC file format for exchanging data with other applications, since it lacks a multi-disciplinary BIM suite of applications.

Implementation

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Initial and Ongoing Pricing/Licensing	✓			ArchiCAD can be purchased as a standalone license or as part of a subscription program. In some countries, licenses can just be rented. It is less expensive than Revit Architecture or Bentley Architecture.
Initial and Ongoing Training		✓		Graphisoft is not in the business of providing paid training, but it provides a lot of free training material online.
Quality of Technical Support	✓			All ArchiCAD users receive free support; users in the subscription programs normally get priority support and access to advanced technical resources.
Quality of Included Documentation	✓			Main Help documentation is available in both HTML and PDF format, and is comprehensively written and illustrated. A separate New Features Guide is available, and video clips showing new features are posted online. Also, sample project files can be downloaded to show how real-world projects are implemented.
Free Online Learning Resources	✓			Many Interactive Training Guides have been developed to allow users to learn the basics of ArchiCAD quickly and easily. They can be downloaded for free from Graphisoft's website.
Support Channel (Resellers and Consultants)		✓		The company has a good network of distributors, resellers, and consultants in many countries over the world.
Availability of Trained Staff		✓		ArchiCAD is available to schools for free, and the wealth of free training material online makes it easy for users to learn the application on their own. But not being the market leader, it is harder to find staff knowledgeable in ArchiCAD as compared to Revit.

Vendor

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Current Market Position		✓		ArchiCAD is trailing behind Revit, but is ahead of all the other BIM applications being used in architectural firms.
Long-term Viability	✓			ArchiCAD's second position among architectural firms, and the acquisition by leading European AEC software vendor Nemetschek, gives it financial stability and long-term viability.
Investment in R&D	✓			Company has been constantly innovating in the last few years and has substantially re-engineered the application, indicating good investment of resources into R&D.
Responsiveness to Feedback and Requests	✓			Graphisoft maintains a "wish list" database that contains all user requests, received directly from users or through partners/resellers. Wishes are classified and prioritized in this system and in each development cycle, emphasis is put on making the new release balanced in terms of new ideas as well as user requests.

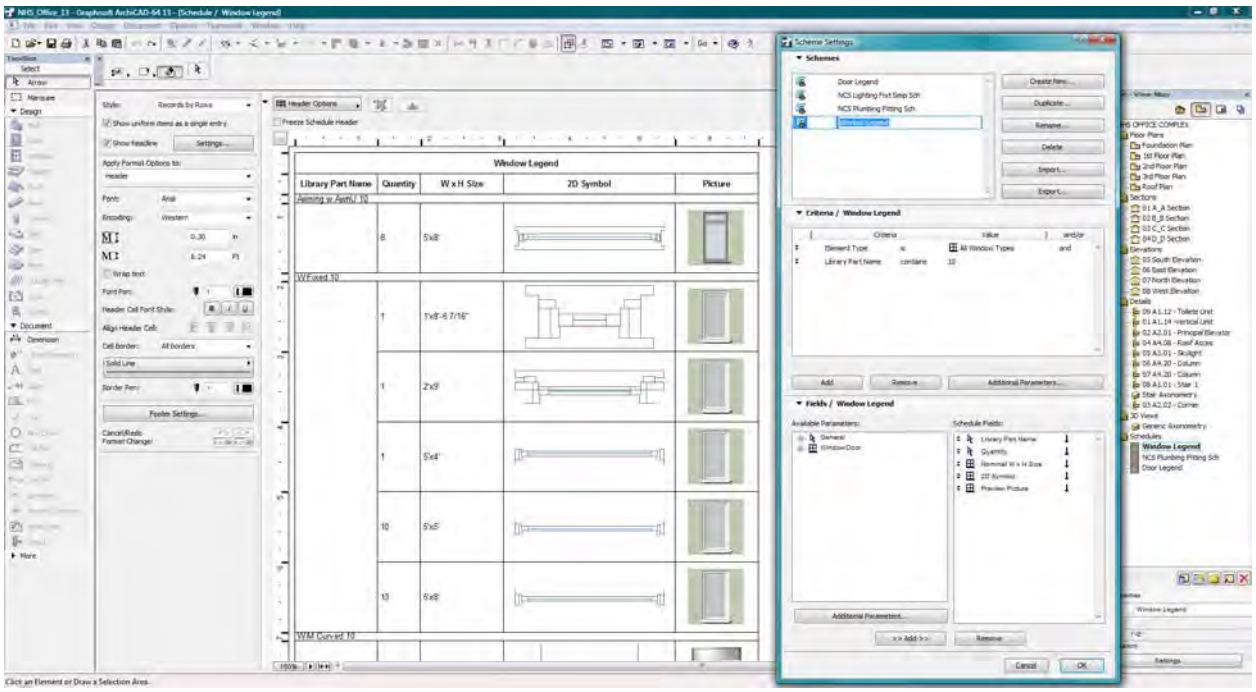


FIGURE 2. Schedules in ArchiCAD have the ability to show both 2D symbols as well as preview pictures.

FIGURE 2. Examples of renderings generated directly in ArchiCAD.

DISCUSSION

This section discusses some of the key features of ArchiCAD in more detail, including the breakthrough collaboration capability introduced in ArchiCAD 13.

Project Setup

ArchiCAD has a centralized model structure, similar to Revit, where the model is typically contained in one file rather than distributed across multiple files. This gives it the same advantages that Revit has of easier project set-up and intuitiveness of use, as there is no need to decide about which part of the model to put in what file—users can get in and start modeling right away. At the same time, by virtue of a more efficient data structure and concise internal representation of building elements using GDL (Geometric Description Language)—a technology developed by Graphisoft for representing intelligent building objects computationally—the model size is significantly smaller than Revit for a comparable building. For example, the file size of the reasonably large and detailed project shown in Figure 4 is only about 25 MB, which also includes all its drawing sheets.

Another way by which ArchiCAD minimizes project file sizes is through use of hotlinked modules, which are used for repeating units such as hotel rooms, offices, or apartment types. The repeating unit is modeled once in a separate ArchiCAD file and is then referenced into the project file as many times as needed. Modifying the source file automatically updates all the instances. An efficient file structure ensures that placing multiple instances of a single hotlinked module in a project does not greatly increase the file size or reduce speed. While hotlinking is mostly used for repetitive units, it can also be used to subdivide large projects into easier-to-handle smaller files.

ArchiCAD has a Project Navigator, similar to Revit's Project Browser, for accessing all the different components of the project. It displays four different components of the project: the *Project Map*, displayed by default, which provides a tree structure of the components of the building model; the *View Map*, which includes all the predefined and custom-created views; the *Layout Book*, which contains the sheets created for the project; and the *Publisher Sets*, which are sets of views defined for various output purposes. Two of these, the Project Map and the Layout Book, are shown in the top and lower image of Figure 4 respectively.

The Project Map is typically used while designing and developing the building model, creating floor plans, elevations and sections, details, 3D views, schedules and so on. The View Map would then be used to save views of the model incorporating desired layer combinations, scale, dimensions and annotations, zoom level, etc. These saved views can be subsequently placed on drawing sheets created with master layouts in the Layout Book. Finally, the layouts can be collected in groups in the Publisher Sets, for publishing to different formats such as PDF, DWF, DWG, DXF, and so on, and for different purposes such as printing, plotting, saving, or uploading to an FTP site. A Project Organizer is available which allows views and files to be moved or copied from one map to the other.

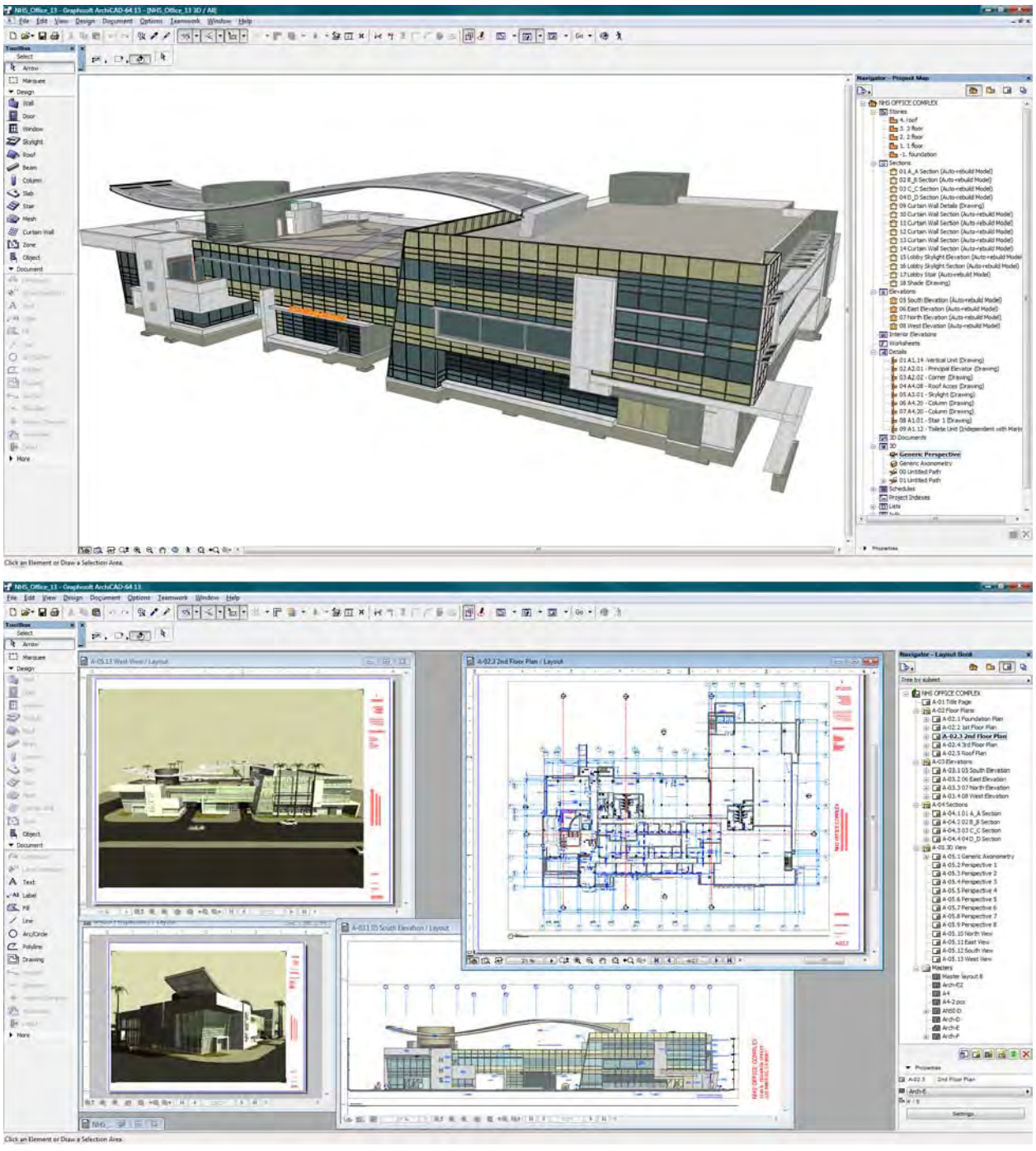


FIGURE 4. A sample ArchiCAD project, showing a 3D view in the top image, and some of its drawing sheets in the lower image.

Thus, the project setup is a little more involved than Revit, and the four different project maps can be confusing, at least for a new user. However, the process is still largely automated. Adding a new level (referred to as a "story" in ArchiCAD) can be done using the Story Settings dialog, and it automatically adds all the corresponding plan views and elevation markers. The default template file that comes with the application has most of the constructs for the project already generated, including plans, elevations, schedules, lists, 3D views rendered both in Lightworks and in Sketch mode, and even the drawing sheets complete with title blocks, as shown in Figure 5. You

can just start modeling and all of these plans, elevations, 3D views, schedules, lists, and sheets will automatically get populated, without needing to be explicitly created by the user. The lower image in Figure 5 shows a sheet with the first floor plan and one of the sketch 3D views that is automatically populated once some elements have been created in the model. This sheet and view did not have to be specifically created. Even Revit does not offer a default template that has this kind of capability. Firms can create their own templates based on the default ArchiCAD template with their own sheet settings, title blocks, display styles, and other settings. Much of the documentation process is then largely automated.

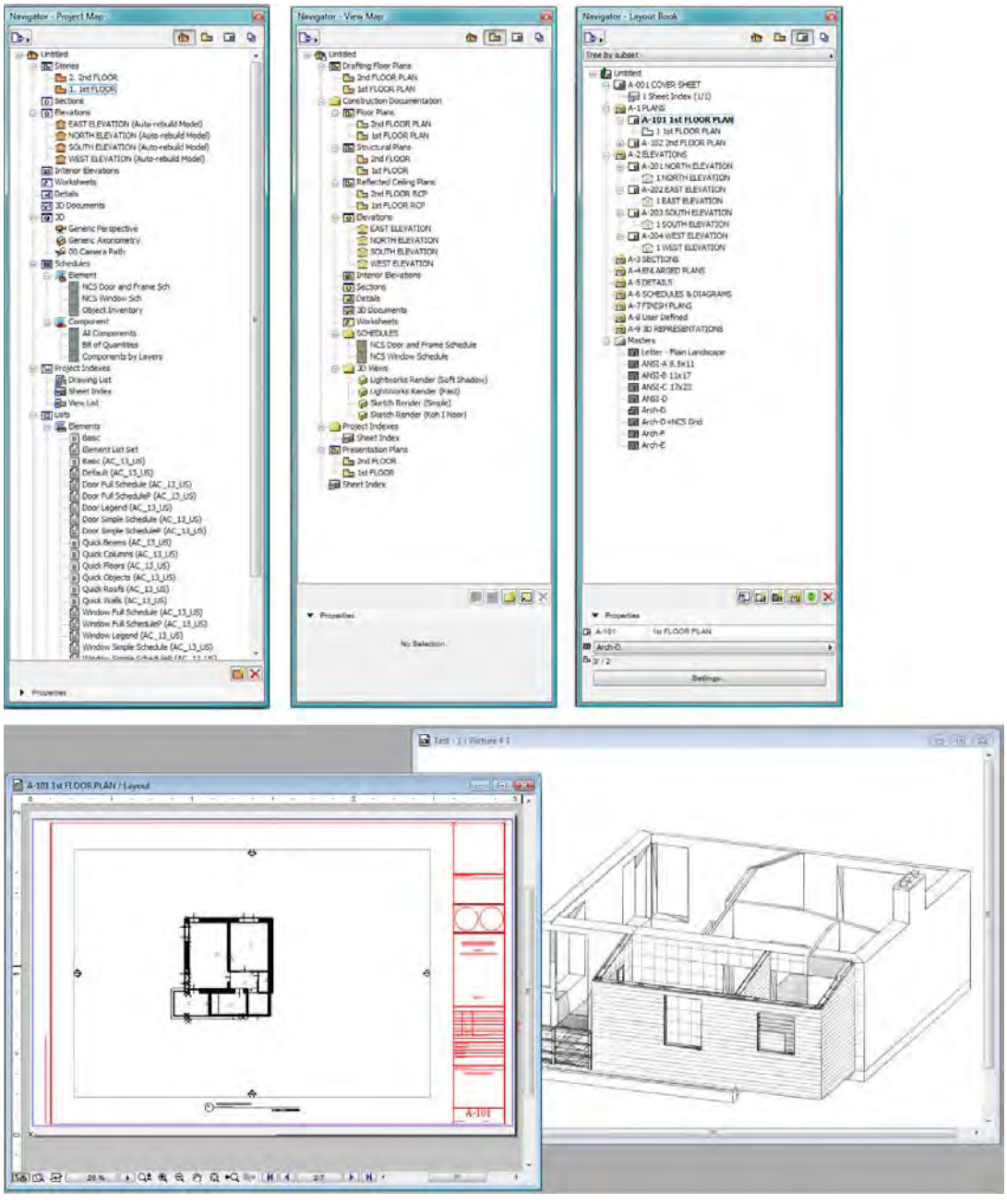


FIGURE 5. The Navigator Maps for a new project, showing the constructs that have already been created by the default project template. The lower images show a predefined sheet and sketch view automatically populated with elements that are being added to the model.

Another aspect of ArchiCAD's project setup is that drawings can be set to either update automatically when the model changes, or frozen at a specific state and then manually updated when required. This makes it different from Revit, where sheets contain live views of the model and are always synchronized with the model. The ability to separate the drawings from the model in ArchiCAD can provide more control over the documentation process and make it easier to divide up the modeling and documentation tasks between members of a project team. A Drawing Manager interface is available to monitor the status of all project drawings, update them if required, or change their update settings. Prior to publishing, however, all the drawings and views are automatically regenerated, ensuring that last-minutes changes will be incorporated.

New Server-Based Collaboration Capability

ArchiCAD includes built-in collaboration capabilities through its TeamWork module, which allows the building model to be divided into parts, across a local network or intranet, for different design teams to work on. It is similar to Revit's worksharing capability, and up until the last release of ArchiCAD, it was beset by the same limitations of inhibiting spontaneous, real-time collaboration. In ArchiCAD 13, released in the summer of 2009, the Teamwork module was completely revamped in order to make collaboration on a BIM model much faster, easier, flexible, and efficient, even for large projects with globally distributed teams. A new component called the BIM Server was introduced, which maintains the complete and up-to-date BIM model of a project. Team members work on the model using ArchiCAD on their local computers. Instead of the whole model needing to be copied back and forth between the master model and the copies—as was the case earlier—only the modified elements are copied using a "Delta Server" technology, which enables the synchronization of the master model and the local copies to happen almost instantaneously, irrespective of the size of the model. The concept is illustrated in Figure 6.

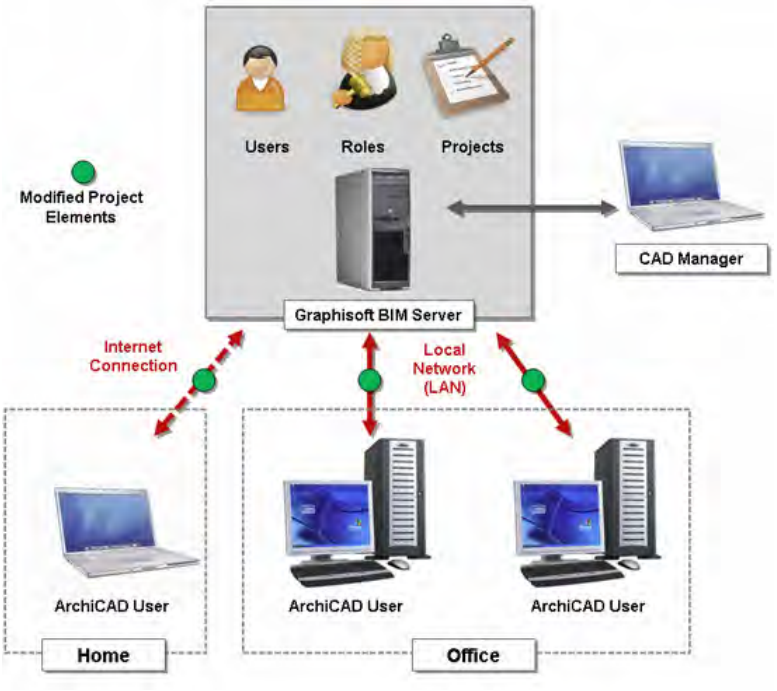


FIGURE 6. The new collaboration solution in ArchiCAD 13, which uses a model server and a technology that detects and transmits only modified elements between the master model and local copies rather than the entire model.

Another key element of the solution is a flexible reservation system. Individual model elements and other project-related data can be reserved and released on the fly, allowing for a dynamic and flexible workflow. There is no need to plan ahead, divide work upfront, and reserve large areas in the project prior to starting work, making them unavailable to other team members. Users reserve only the elements they currently need and can release them immediately after the work is done. The technology comes with an intuitive interface that makes it easy to use. The Teamwork palette lets users reserve elements, release them, send and receive changes, and see who else is working on the project and the parts that they are working on. One of the options for viewing the workspace allows it to be color-coded so that the elements reserved by different users are displayed in the color assigned to them, making it immediately clear who is working on what (see Figure 7). Hovering the mouse over an element shows whether it has been reserved, and if so, by what user. If another user logs on and reserves an element, that change is immediately reflected in the workspace display of all the users.

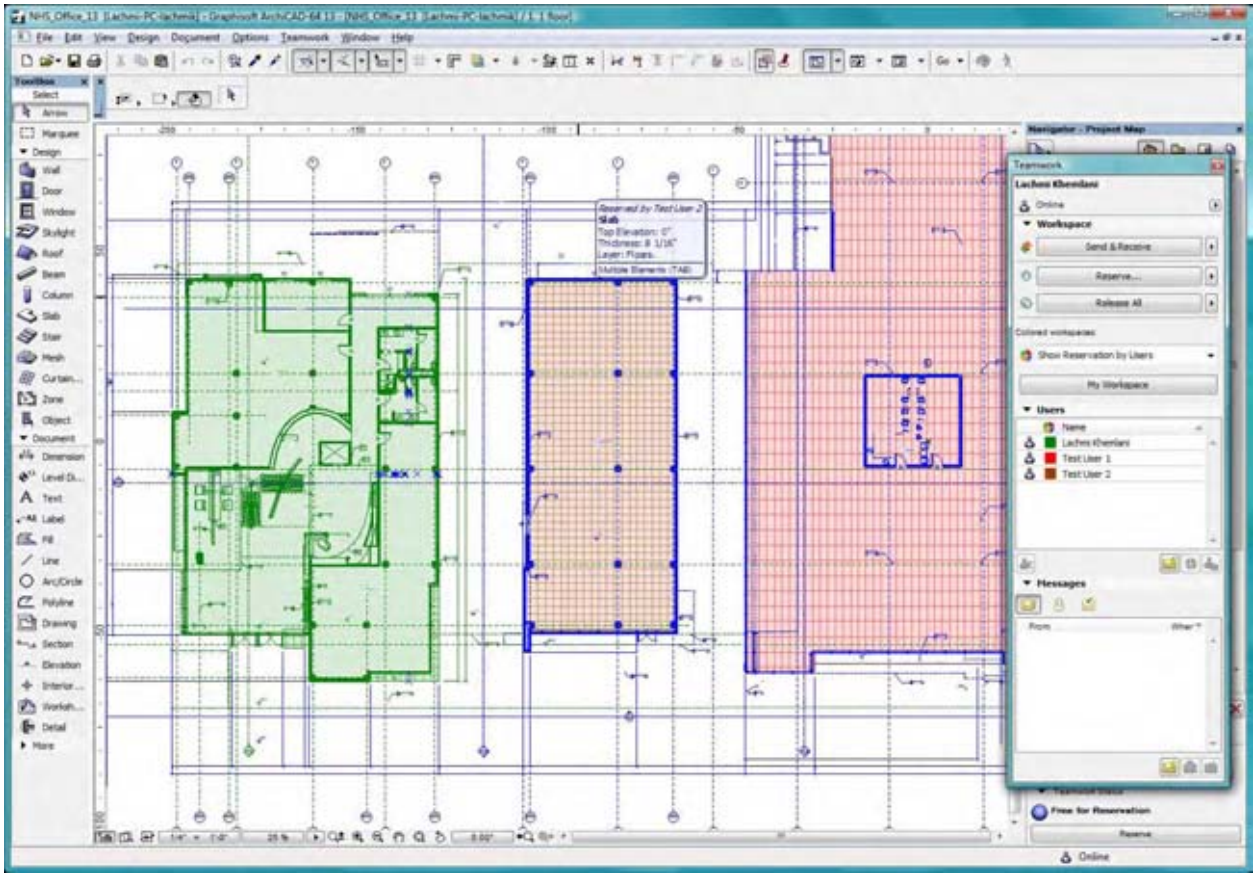


Figure 7. The Teamwork palette showing the various elements reserved by the different users who are working on the project simultaneously.

The solution also has a built-in instant messaging feature that allows requests for elements between team members to be instantly communicated and granted, making the collaboration process quick and fluid. The process is illustrated in Figure 8. In Figure 8-a, a user uses the Request command to ask for an element reserved by someone else, as they need to work with it. Figure 8-b shows how that message is immediately communicated to that user by appearing in the Messages section of their Teamwork palette. They can review it and use the Grant Request option to quickly accept the request. This is again immediately communicated to the first user in their Messages section, as shown in Figure 8-c, and the requested element is now available to them for modification.

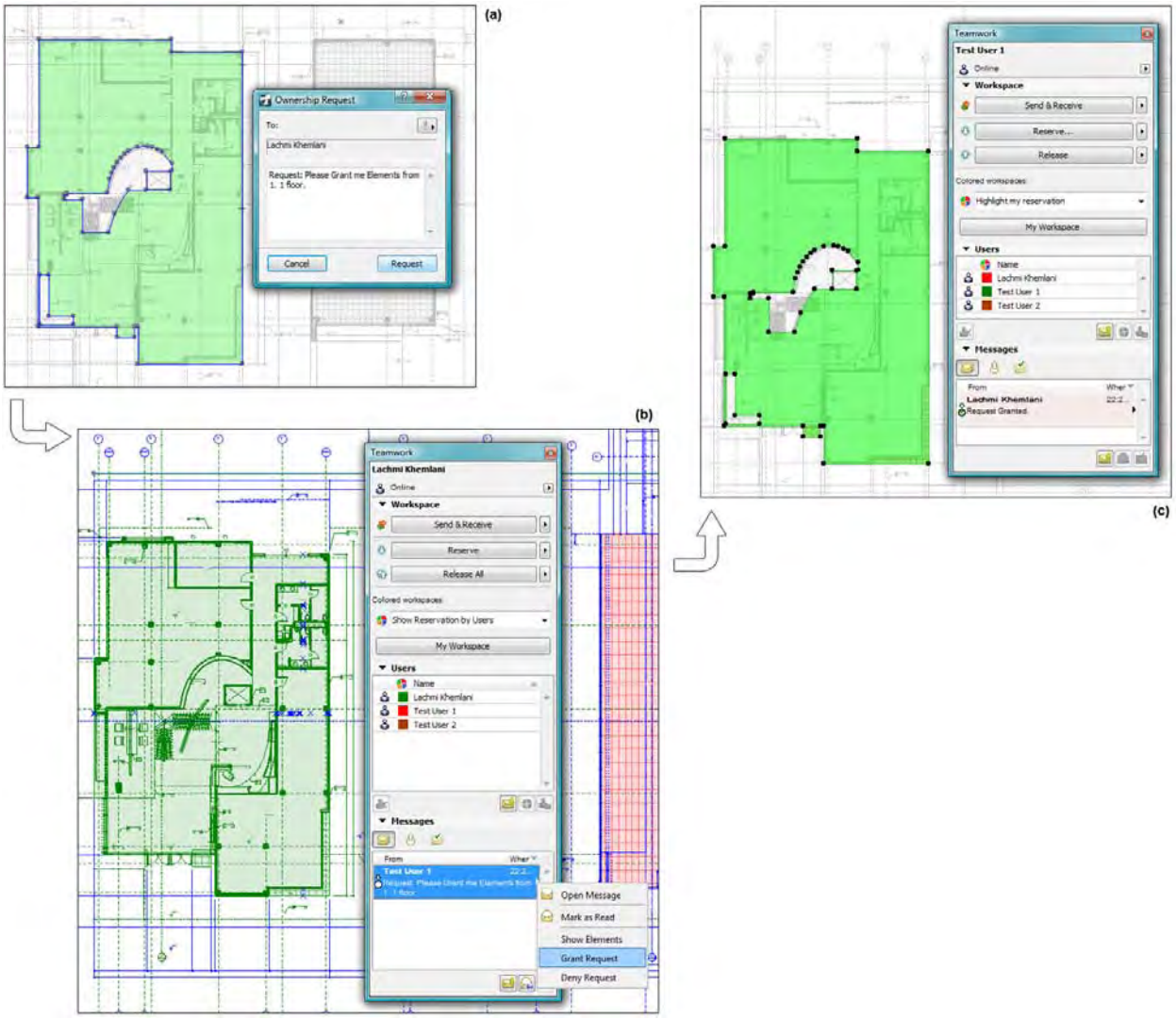


Figure 8. Requesting an element that is reserved by another user, shown in (a), the communication of that request, shown in (b), and the granting of it, shown in (c), making that element now available for modification.

It should be noted that the changes that are being made by the various users to the elements they have reserved and are working on are not instantaneously seen by everyone—for that, the changes first have to be posted by the users through the "Send and Receive" option in their Teamwork palette. It can then be seen by other users, but only when they too, in turn, use the same "Send and Receive" option to synchronize their model with the master model on the server. Since only the changed elements are sent, the process is very fast. However, it does lead to the possibility that conflicting edits to the model by different users may create some inconsistencies. It remains the responsibility of the design team to ensure that their individual additions and edits to the model are consistent and there are no design errors.

There is no additional cost for the new server-based collaboration capability in ArchiCAD 13; it is included in the cost of the application. It is especially beneficial for large firms with globally distributed teams as it can allow team members to work together easily and quickly in real-time on modeling projects, from anywhere in the world where

a standard broadband Internet connection is available. The technology is sophisticated, yet it has been implemented in a manner that makes it easy and intuitive to use, which is no mean achievement. Under the hood, the data structure of ArchiCAD has been completely reengineered so that the individual building elements can work with a database server. While the database technology in itself is not new, what is innovative here is that it has been applied to a BIM application. This may help to explain why other BIM applications don't have this capability yet—it would require some fundamental changes to how their data is structured internally, calling for substantial development time and resources.

For project communication with clients, contractors, consultants, and other team members not using ArchiCAD, Graphisoft provides a free Java-based viewer called Project Reviewer that allows published documents to be opened, reviewed, and redlined. There is also Project Mark-Up, a redlining utility within ArchiCAD itself for facilitating communication between designers. It allows problematic elements to be highlighted, and elements to be created or modified in mark-up mode, with options to set mark-up colors and display information such as designer's name, date, and comments.

Interface

ArchiCAD's interface has been redesigned in recent releases to improve usability and reduce clutter. The model navigation tools are excellent and include a 3D Explore mode which allows easy game-like navigation and exploration of the model in a perspective view. The 3D Orbit mode can be used even in the middle of an editing operation, which is extremely helpful. Two other useful interface features, demonstrated in Figure 9, include the ability to see the most relevant information about any element—including its attributes and parameters—by selecting it or moving the mouse over it with the Shift key pressed. This helps the designer to quickly identify elements at a glance in large and complex projects. Another useful feature is the Tracker, which is automatically activated during any drawing, modeling, or editing operation, and displays the numeric values relevant to the current operation, allowing them to be numerically over-written. It is not as powerful as Revit's heads-up display but helps to create and edit models with precise input.

Figure 9. The ability to see element information by selecting it (left image) and using the Tracker to make precise modifications (right image).

A recently introduced Rotate Orientation option allows the project view (floor plans, worksheets, details, etc.) to be rotated while keeping the project coordinates constant. This makes it much easier to work with models that have odd angles—the user can simply orient the part that they are working with parallel to the screen, as shown in Figure 10. The top image shows the original view, while the lower image shows the rotated view. The dimensions automatically adjust based on the orientation so that they are still readable. In addition, other annotation elements such as text, labels, markers, and zone stamps have a "Fixed Angle" option that can be selected so that they also adjust automatically to match the oriented view. This option has been activated for the zone names in the example shown below, as shown, so they stay horizontal even when the view is rotated.

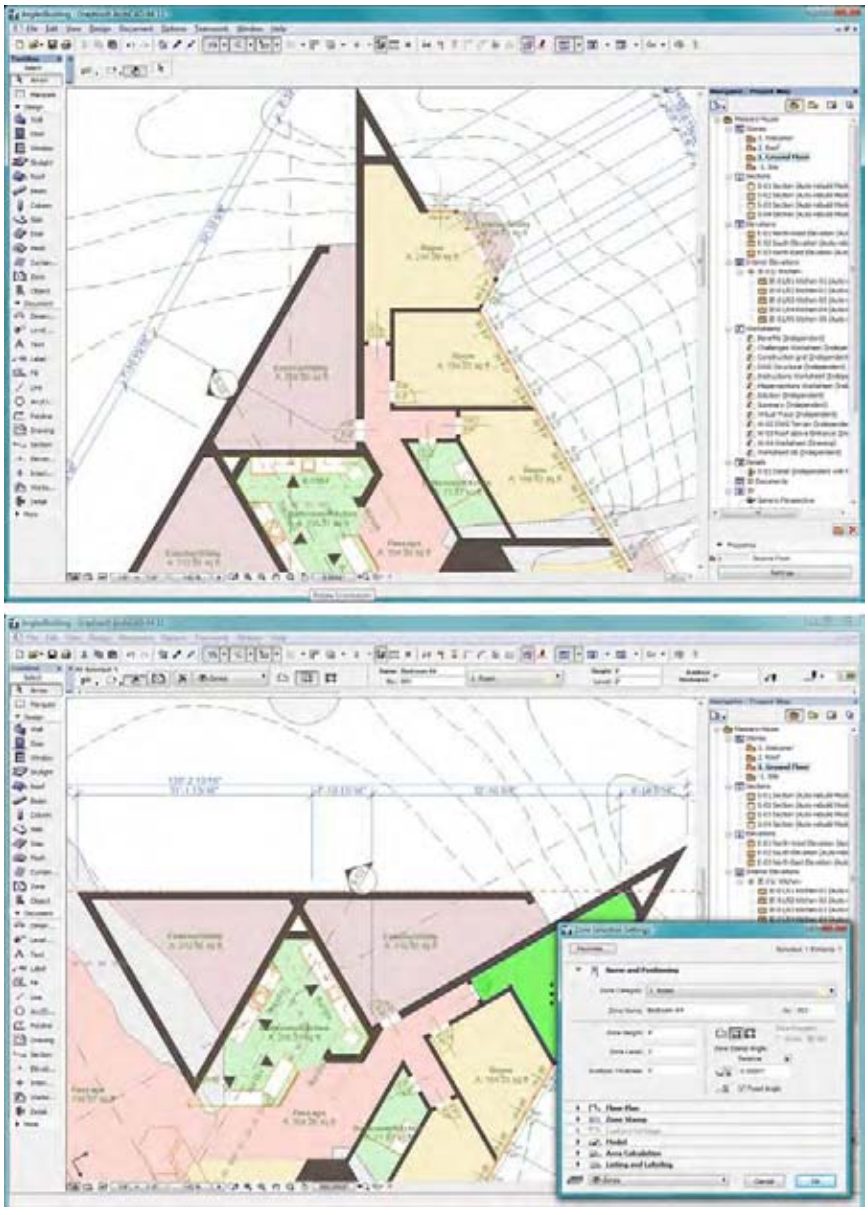


Figure 10. Using the Rotate Orientation feature in ArchiCAD 13 to orient the view so that the slanted wall is parallel to the screen. The Zone dialog is also displayed, showing the "Fixed Angle" option activated with the angle specified as 0, which keeps the zone names always horizontal, even when the view is rotated.

Another innovative interface feature in ArchiCAD is a "Virtual Trace" technology that simulates the virtual tracing paper methodology architects have traditionally used for producing and coordinating their drawing sets. It works by providing the ability to display a live reference view alongside the currently active model view or drawing layout. It can be used as a visual reference for modeling, as a temporary editing aid, and for comparing or coordinating drawings and models (see Figure 11). References are easy to place and reposition, there is full control over how they appear relative to the active view, the active and reference view can be switched in one click, and there are several aids for easy comparison of the two views, including the Splitter feature shown in Figure 11.

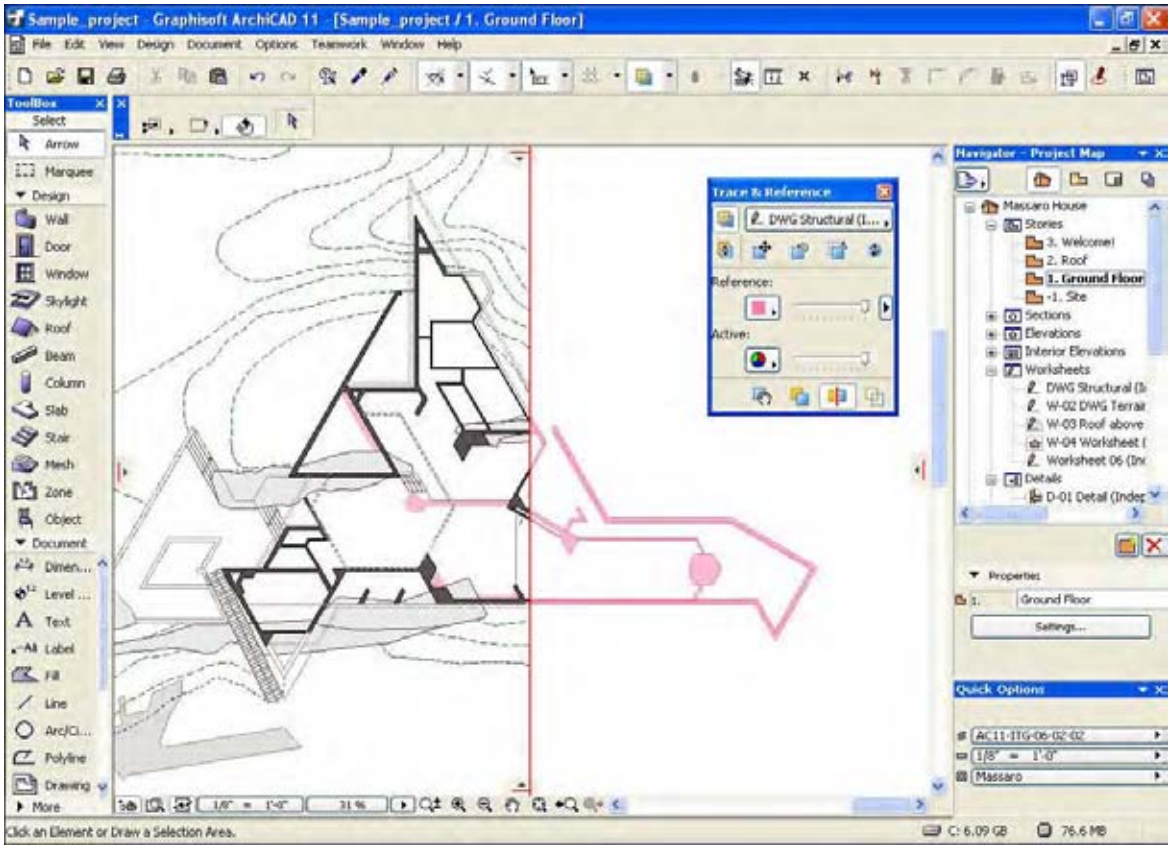


Figure 11. Using the Splitter tool in conjunction with the Virtual Trace functionality to split the screen and compare a structural drawing, opened as a reference, with the floor plan, which is the active view.

On the flip side, there is no built-in associativity between building elements in ArchiCAD, which would have allowed for faster creation and editing of the model. Even something as basic as wall connectivity is missing. If you move a wall, the walls connected to it don't automatically stretch to maintain connectivity. The only way to stretch a wall is to draw a marquee around all the nodes that need to be stretched, which is an extremely tiresome way of editing. It is this lack of associativity that makes ArchiCAD's interface seem a lot less fluid and intelligent, especially in comparison to Revit, which has a much higher level of built-in relationships and associative behavior. Another critical interface problem in ArchiCAD is the lack of an automatic tiling option that can arrange open windows neatly in the workspace, so that users can work with plan, elevation, and 3D views together. This is so common in all 3D applications that it is extremely difficult to work without it in ArchiCAD. Also, the dialog boxes in the application tend to be overloaded with graphic and textual information, which can make them quite overwhelming.

Functionality

ArchiCAD has a fully developed toolset for creating walls, columns, beams, roofs, slabs, meshes, zones, stairs, and curtain walls. It has the unique capability of allowing walls, beams, and columns to be easily slanted or inclined, simply by specifying the desired slant angle in their Settings dialogs, as shown in the top image of Figure 12. For even more complex walls, beams, and columns, custom cross-sectional profiles can be defined, which can be saved for re-use in other projects. The ability to slant walls or apply custom profiles to them also works on curved walls, allowing for more modeling freedom, as demonstrated in the lower image of Figure 12. These elements retain their BIM nature; so, for example, doors and windows can still be inserted in these complex walls, and they can also be aligned with the angle of the surface instead of being vertical, if required. The application automatically creates the correct floor plan representation at every level of the building for these complex elements. ArchiCAD remains the only BIM application to date to have this kind of modeling capability available so easily. While it does not give ArchiCAD the ability to model completely freeform shapes, it allows the application to easily model a building with some usual geometry without giving up on the benefits of using a BIM application.

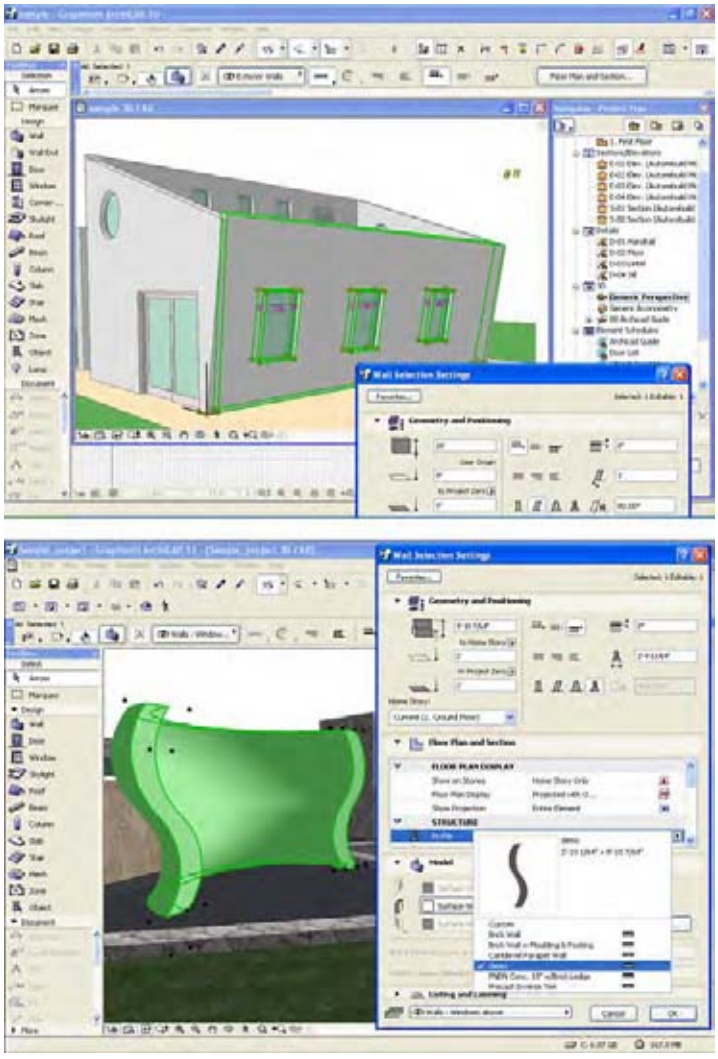


Figure 12. The ability to create non-vertical walls introduced in ArchiCAD 10. The top image shows an inclined wall defined by a single slant angle, while the lower image shows a complex curved wall defined by a custom cross-sectional profile.

ArchiCAD does not have any dedicated tools for space planning and programming, which is a limitation it shares with many of the other BIM applications including Revit. However, it also has another problematic aspect related to spaces, which is that it uses a "zone" element instead of a "space" element—thus, there is no distinction between rooms/spaces as commonly defined by a single enclosure, and a larger collection of spaces that can come together as a zone. Sections in ArchiCAD cannot display zones at all. Also, ArchiCAD does not automatically detect the vertical footprint of a zone by elements such as slabs and roofs but uses a numeric value instead, so that to calculate the true volume of a zone under a complex roof, you have to first specify its height to be greater than that of the roof and then trim the zone against the roof. At some point, ArchiCAD needs to rethink its zone element and have a separate entity for a space or a room, which is one of the basic elements of building design.

Many of the documentation-related capabilities in ArchiCAD have already been described in the Project Setup section. Other highlights include the ability to create any view from anywhere, for example, creating a section by referencing another section. A wide variety of displays styles and fill types allow high-quality presentation drawings to be created, as shown in the elevation sheet window of Figure 4. There is an automatic exterior and interior dimensioning capability, and an Interior Elevation tool that can be used to quickly generate all the interior elevations of a space. Also, in addition to the full plan, elevation, and section drawings and the traditional close-up detail views, ArchiCAD allows the use of "worksheets" that are optimized for creating partial floor plans and partial sections, as shown in Figure 13. Worksheets can also be created to add images, charts, diagrams, and so on that are independent of the model but useful for the documentation of the project.

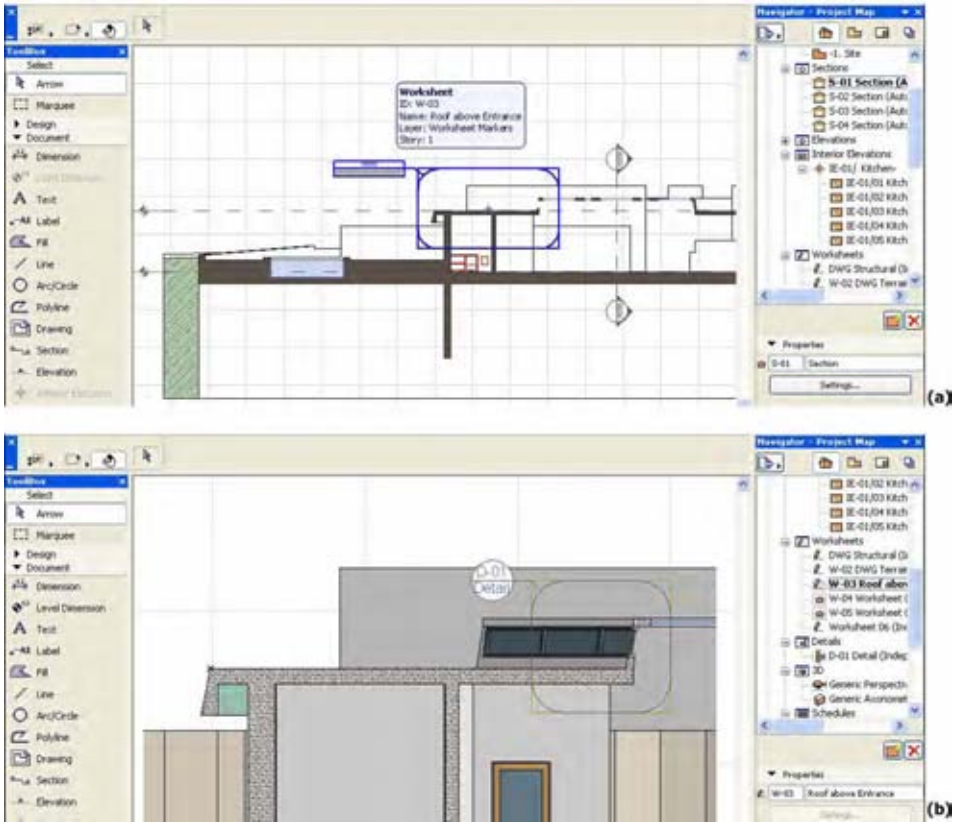


Figure 13. Use of worksheets as opposed to details. (a) Selecting a portion of a section view to create a worksheet. (b) The worksheet with the selected portion of the section developed in more detail. It also includes a further link to a detail view.

Another unique feature in ArchiCAD is the ability to create 3D documentation from the model to supplement the traditional 2D construction documentation that architects create. Users can capture any 3D view of the model, create a 3D document from it, and add text, labels, dimensions, and 2D drawing elements, as illustrated in Figure 14.

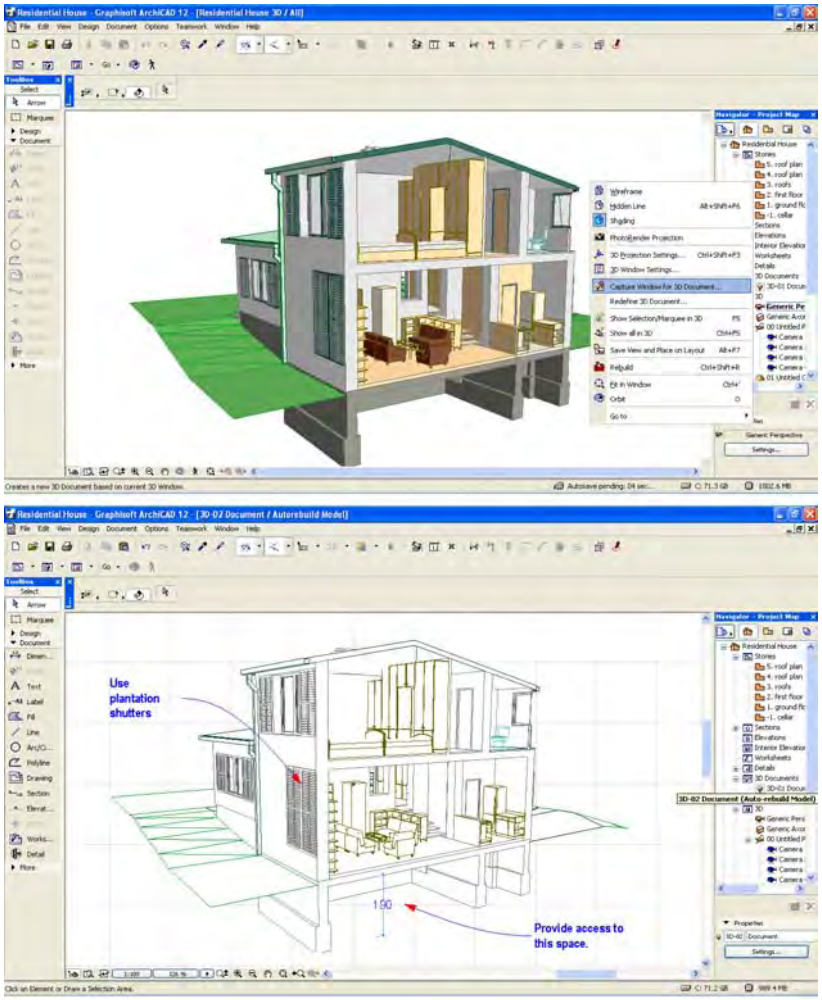


Figure 14. Creating a 3D document from a 3D view in ArchiCAD, and adding annotations and dimensions to it.

While ArchiCAD has a number of add-on tools such as the MEP Modeler and the Virtual Building Explorer, its EcoDesigner add-on for energy analysis is especially noteworthy, since it is the only analysis application so far that is fully integrated within a BIM application. Designed to be comprehensive, yet quick and easy to use, EcoDesigner calculates the energy consumption, carbon footprint, and monthly energy balance of a proposed design, enabling architects to evaluate multiple design alternatives at the early design stage and find those that satisfy desired performance criteria (see Figure 15). They can fine-tune aspects such as building orientation, building volumes, area and orientation of glazed surfaces, and shading options, all of which can greatly impact energy performance. While this energy analysis capability is not revolutionary in itself, what is significant is that it is integrated within ArchiCAD, bringing the "one-click evaluation" vision for BIM to reality at last. Architects can now perform a quick energy estimate even on complex projects, without being a building energy expert, and without leaving their BIM application.

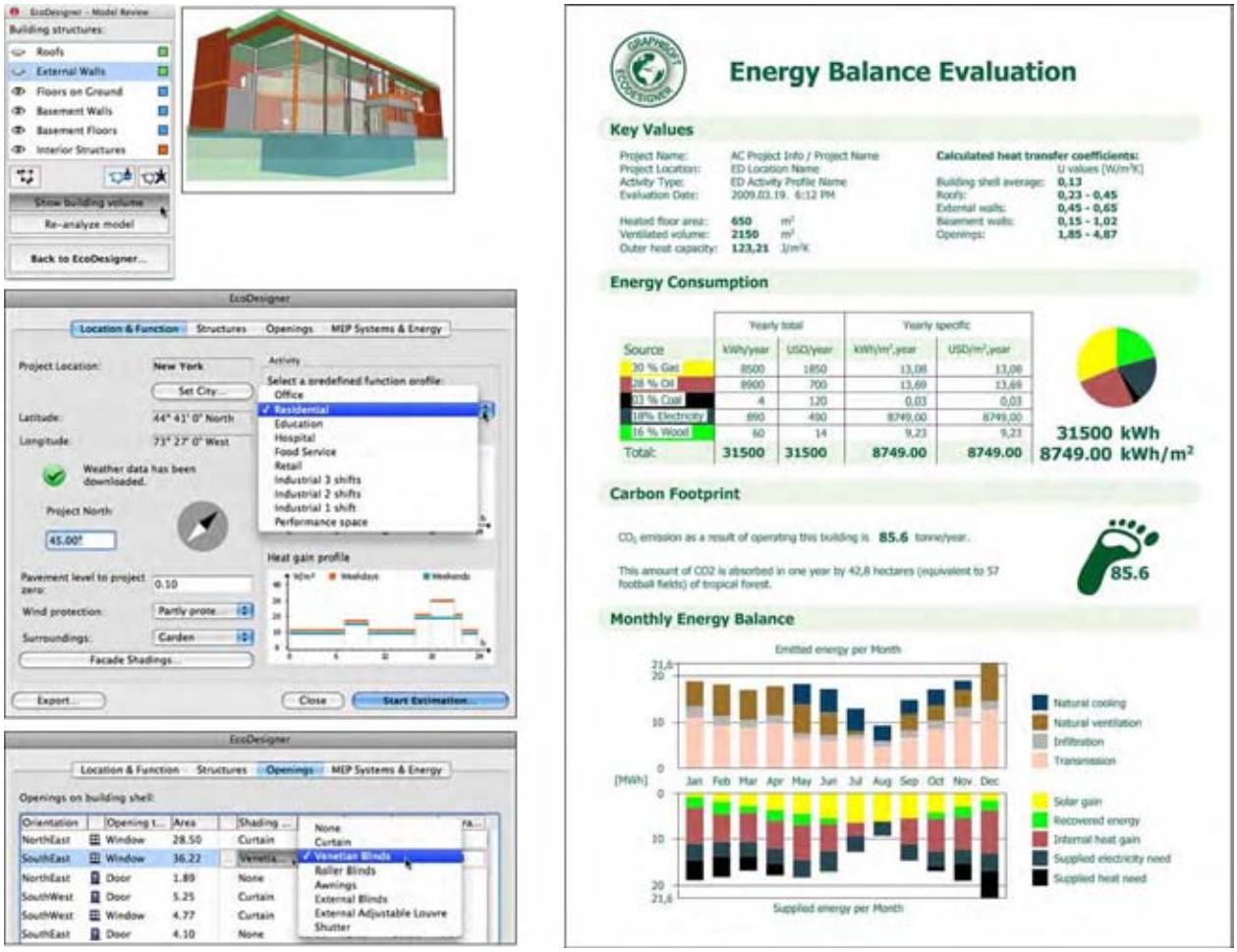


Figure 15. An example of the energy analysis results calculated by EcoDesigner for an ArchiCAD project.

And finally, special mention must be made of the entirely new training concept called the Interactive Training Guide that Graphisoft has pioneered. It is a free download from Graphisoft's website and includes a collection of exercises organized in chapters that take you step-by-step through different aspects of the application. All the steps are captured in narrated movies that can be opened within ArchiCAD, allowing you to follow and repeat the exercises as presented in the movies, at your own pace. Figure 16 shows a screenshot of the first Interactive Training Guide that was introduced in ArchiCAD 10 in 2006, which took the user though the process of developing an architectural design project from scratch. The movies are nicely synchronized within the application, so that once you complete a step by watching the associated movie, the movie for the next step is automatically loaded. It comes with the pre-set ArchiCAD project files for the different chapters, allowing users to focus on learning the core material without worrying about the settings. In subsequent years, more Interactive Training Guides focused on different aspects of the application have been released, allowing users to learn the basics of the application on their own, as well as some advanced concepts, without being forced to rely on professional training. Such an innovative and effective approach to training is unique, not just among BIM applications, but among the larger universe of CAD applications as well.

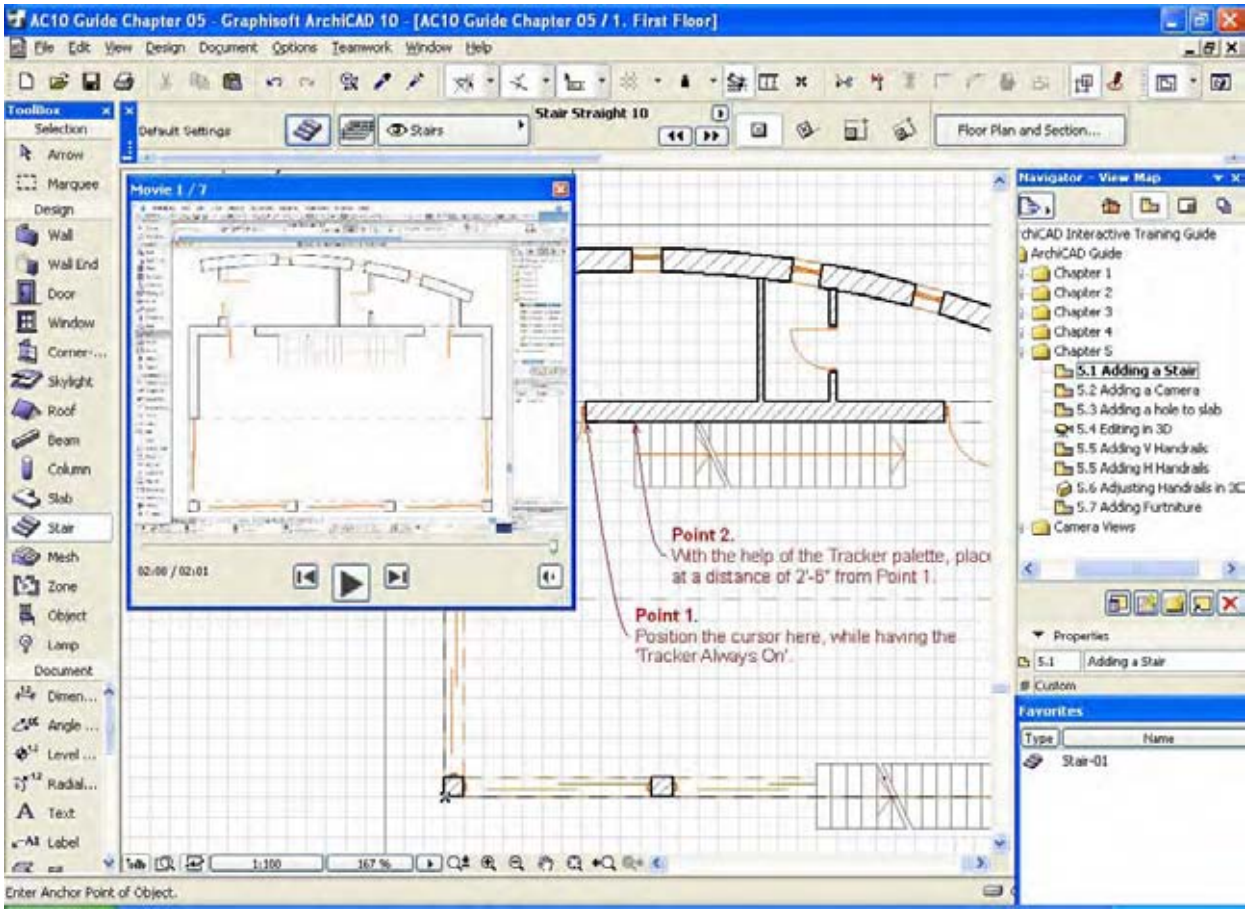


Figure 16. The Interactive Training Guide that was introduced in ArchiCAD 10 for hands-on interactive training for users new to ArchiCAD.

CONCLUSION

Graphisoft is a technologically sound company that has been continuously innovating and improving ArchiCAD, particularly in recent years. Its acquisition by Nemetschek has provided it with financial stability, so firms implementing ArchiCAD can be assured of its long-term survival. Its independent operation lets it continue to be developed as planned by its core team, and allows it to be very nimble and responsive to feature requests from users, most of whom are extremely happy with it. Despite being part of a large company, it has the advantage of being able to operate like a small one.

It is extremely commendable for ArchiCAD that it is the first BIM application to include a server-based collaboration capability as well as support both multi-processing and 64-bit computing. All of these capabilities have required portions of the software to be re-written: for example, to support multi-processing, tasks had to be sliced up so that they could be tackled simultaneously by the various processors; and for the collaboration capability, the data structure of ArchiCAD had to be completely reengineered so that the individual building elements could work with a database server. It takes substantial development time and resources to re-engineer applications in this manner, and Graphisoft deserves kudos for making this investment and showing that there is a solution to the collaboration problem that has been dogging Revit for so long. While it is still too early to judge

whether this is indeed a breakthrough technology for the AEC industry or not, it is definitely very impressive, and despite being very sophisticated, it has been implemented in a manner that is very intuitive and easy to use.

That said, ArchiCAD also has some serious deficiencies when compared to industry leader Revit, the most critical being that it is a single disciplinary solution and relies heavily on the IFC for integrating with other disciplinary applications. Its MEP Modeler add-on cannot substitute for a full-blown BIM MEP application, but it is a good first step. It needs a structural engineering add-on as well, in addition to tighter integration with other single-disciplinary engineering solutions like Tekla Structures. The lack of associativity between building elements is a serious limitation in ArchiCAD that really hampers ease of use. It also needs to improve its conceptual design and freeform modeling capabilities to make them on par with other BIM applications. Until ArchiCAD can address these limitations, it is likely to trail significantly behind Revit in adoption. But given the recent track record of the company when it comes to innovations, it seems likely that Graphisoft will turn its attention to tackle these issues now that the collaboration problem has been addressed, and attempt to expand the use of ArchiCAD to large firms in addition to the small and medium size firms that have been its forte so far.

Allplan Architecture

Allplan is the flagship product of the German company, Nemetschek AG, which was founded all the way back in 1963 and has been developing software products for the building industry since then. It is a public company and the leading AEC software vendor in Europe. The company's portfolio has now expanded well beyond Allplan to include nine other brands comprising solutions for building design, engineering, construction and facility management as well as visualization (see Figure 1); they are available in over 20 languages and collectively used by over 270,000 customers in 142 countries around the world. Both ArchiCAD and Vectorworks, two of the other BIM applications that are included this study, are also part of Nemetschek. Allplan, however, continues to remain the company's core product with a user base of over 60,000 customers worldwide.

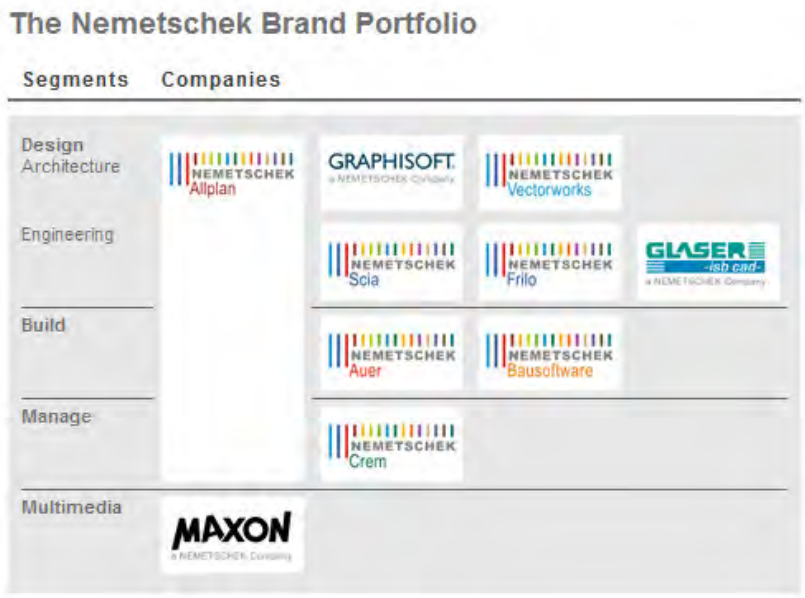


FIGURE 1. All the products that come under the Nemetschek portfolio of AEC applications.

Allplan has a long history in the AEC industry, with the 2009 version being the 20th release of the application. Similar to ArchiCAD, it had object-oriented CAD capabilities from very early on and was considerably more powerful and sophisticated than most of the CAD applications in the pre-BIM days. Because of its long history and decades of development, Allplan is replete with features and includes the full functionality of a CAD application, including drafting, 3D modeling, visualization, and animation. Like Vectorworks, however, it has been a little late getting on the BIM bandwagon. It was only in 2008 that Nemetschek rebranded Allplan as a BIM application and introduced some functionality to make it better adapt to the BIM workflow. It also expanded the application into a multi-disciplinary platform, with separate products for architecture, engineering, and building services, and subsequently introduced solutions for cost planning, cost estimating, and facilities management for the same platform. All these applications work as an integrated multi-disciplinary suite, allowing an Allplan model created by the architect to be reused and edited in any of the other Allplan applications for engineering. In fact, the Architecture, Engineering, and HVAC solutions actually come as modules within Allplan, which means that only one installation is required for all three solutions (see Figure 2). Allplan is constantly adding more modules, such as a dedicated module for timber construction (see Figure 3) and a new module specifically for building alterations.

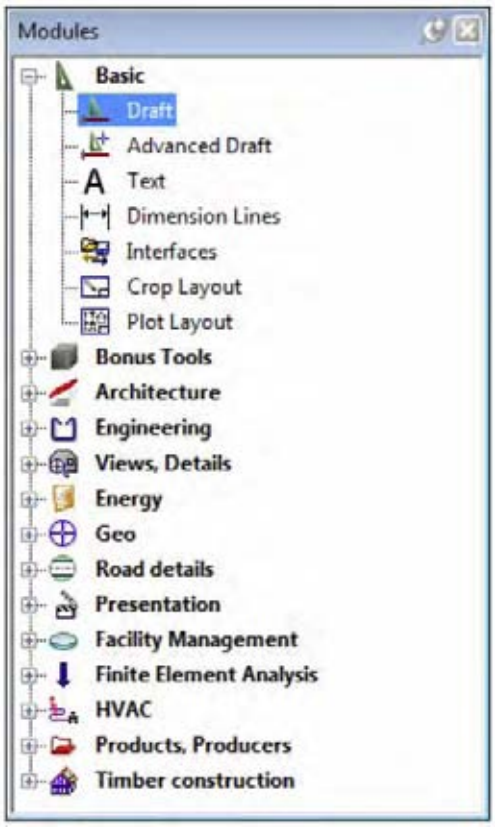


FIGURE 2. The different modules of Allplan providing a range of functionalities for building design.

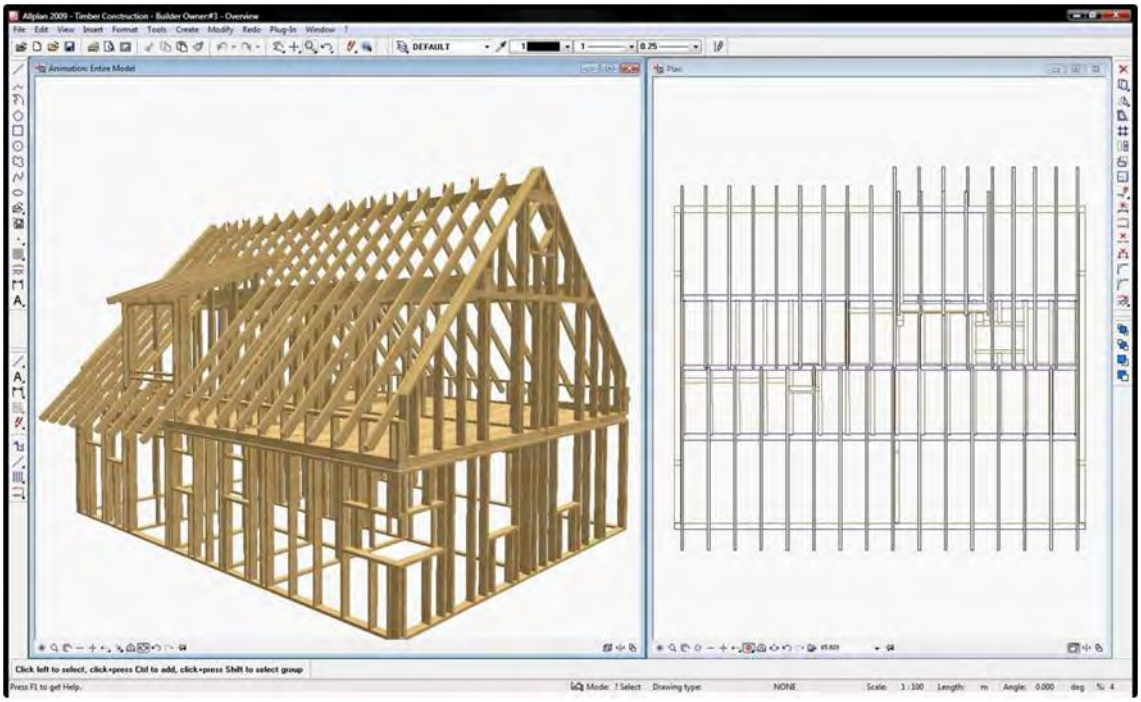


FIGURE 3. The new Timber Construction module of Allplan.

EVALUATION SUMMARY

Key Strengths

- Is part of a tightly integrated suite of applications for design, engineering, cost estimating, and facilities management
- Many additional modules being constantly developed to add to the capabilities of the application
- Extensive repertoire of CAD, 3D modeling, and building modeling capabilities with a large array of options for each tool
- Comprehensive 3D modeling tools allow complex organic forms to be created
- Powerful and sophisticated Façade tool makes it very easy to design complex curtain wall systems
- Includes bidirectional integration with Cinema 4D for creating sophisticated renderings, and has dedicated interfaces to export the model to other rendering applications
- High degree of usability with shortcuts, interface customization, and wizards for element creation
- File-based project structure makes collaboration easier and enables it to be easily used on large projects and by distributed project teams

Main Limitations

- Project setup is very different from any other BIM application and can initially be complex and confusing
- File-based collaboration is not real-time and lacks flexibility
- Has no capability to convert a massing model into a BIM model
- Lacks built-in associativity between building elements, which increases the time needed for modeling and editing
- Sections and elevations have to be regenerated to show changes to the model instead of being automatically updated
- Built-in rendering is not on par with other BIM applications, with more sophisticated renderings typically created using its integration with Cinema 4D
- More expensive than comparable BIM applications
- Many aspects of the application are not properly described in the documentation, making it difficult to learn the application
- Very little US presence so far, and no concerted effort to target the US market

Price

- 5,995 Euros

DETAILED EVALUATION

Application Repertoire

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Space Planning/ Programming		✓		A Space Allocation Wizard is available (as a separate module) which allows a room list to be entered in a table or imported from Excel. Based on this, spaces can be automatically created and used to explore different spatial layout options. Spaces can then be used to generate walls. But there are no capabilities for bubble diagrams, adjacency matrix, and space links with scores, similar to what Vectorworks has.
Conceptual Design/ Mass Modeling		✓		Includes an extensive 3D modeling toolset that can be used to create massing models. However, these are not as intuitive for conceptual design as tools like SketchUp. A tablet-based sketching application, Allplan Sketch, is available that is fully integrated with Allplan, but it is for 2D sketches rather than 3D conceptual models.
Detailed Modeling	✓			Comprehensive toolset for building objects including doors, columns, beams, slabs, corner windows, chimneys, railings, foundations, stairs, roofs, rooms, as well as many detailed building components. The Façade tool allows complex curtain wall systems to be created very easily. A Geo module is available for site design.
Schedules and Reporting	✓			Extensive scheduling and reporting capabilities. The format and layout of schedules can be customized, and can include sketches of the objects. Schedules can be associative; it's also possible to export them to Excel while keeping bidirectional associativity.
Quantity Take-off	✓			Advanced quantity take-off capabilities, with the ability to precisely calculate quantities, generate lists and schedules, or transfer data to systems used for tendering, ordering and billing. Even quantities that have no graphical presentation (e.g., power sockets, finishes, etc.) can be included.
Photorealistic Renderings		✓		Built in renderings are of acceptable quality. There is bidirectional integration with Cinema 4D for more sophisticated renderings, and dedicated interfaces are available to export the model to other rendering applications. (*See Figure 4*)
Animations		✓		Basic animation capability that allows the camera movement around a target point or along an arbitrary path to be saved as video clip.
Real-time Model Exploration			✓	Real-time model exploration is only supported by a special camera mode in the animation window.
Construction Documents	✓			Extensive set of CAD tools that allow construction documents to be produced according to different national standards. Content and layout of the drawings can be adapted extensively by means of drawing types, plot sets and display favorites.
Coordination/ Clash detection			✓	No internal clash detection capabilities.

Fabrication			✓	No special capability beyond the ability to export detailed geometry information to a database. No native support for STL or STEP formats commonly used for fabrication.

Intrinsic Nature and Capabilities

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Intuitiveness and Ease of Use		✓		While the modeling interface is quite intuitive and it's possible to work completely in full screen mode using shortcut keys and mouse clicks, some interface aspects hamper usability: a project can only be opened if its path is configured using an associated application; lack of associativity slows down modeling and editing; and sections and elevations do not update automatically.
Ease of Project Setup			✓	Project setup is file based and is quite complicated, with predefined files associated with different levels of the building structure. Sections and elevations have to be generated and updated manually.
Information Re-Use		✓		Walls can be derived from a space plan, and complex curtain wall systems can be created from 3D geometry. However, it does not have functionality similar to Revit's BuildingMaker that can quickly generate floors and walls from a massing model.
Modeling of Organic Building Forms		✓		3D modeling tools are available to model complex geometry, but it lacks the full freeform modeling capability of an application like Rhino. Interfaces to Cinema4D and Rhino are available to import organic shapes.
Automation of Tasks		✓		There is some task automation such as roof framing, and creation of stairs, railings, and curtain walls from a few parameters, taking into account the geometry specified. Based on existing walls and other building objects, rooms including labels and finishing can be created automatically.
Creation of Parametric Forms			✓	Individual building objects such as doors and windows are parametric. Objects such as walls, slabs or windows that are associated with reference planes in the plane manager automatically adjust when the level of the plane is modified. But there is no sophisticated parametric modeling capability of the kind provided by Digital Project or Bentley's GenerativeComponents.
Associative Behavior of Building Elements			✓	It does not automatically maintain relationships between elements when they are moved or otherwise modified. This diminishes the fluidity and ease of use of the application.
Guarantee of Model Integrity			✓	There are no modeling constraints, so there is no guarantee of model integrity.
Availability of BIM Content		✓		Allplan comes with predefined content for objects like windows, doors, curtain walls, and also with predefined tables of sections (e.g. steel sections) or fixtures from industrial suppliers (e.g. Halfen channels). Also, dedicated country-specific content packages are available. Additional content can be imported in supported file formats. But there is no third-party creation of BIM content.

Customization Capability	✓			Allplan supports a high degree of customization. The user interface, including tool palettes, tool bars, short cuts, and mouse buttons, can be changed. Users can define their individual objects (such as windows and doors) and control their presentation in different scales and drawing types. Office-specific wizards can be created and used for more efficient modeling and consistent representation.
Support for 3D Printing		✓		It is only supported through the VRML file format rather than through the more common STL format.
Multi-Processing Support		✓		There is support for multi-processing for some tasks and modules, but it has not been implemented for the complete application.
64-bit OS Support			✓	The application is only 32-bit at this time.
Cross-Platform (Windows, Mac)			✓	Allplan Architecture is a Windows-only application.

Issues Specific to Large Firms

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Model Performance		✓		Since the model is distributed across multiple files, the performance is not as slow for large projects as it is for centralized BIM applications. However, there are no special capabilities to speed up performance when the complete model is opened up.
Model Sharing Technology		✓		The project is divided into files and different users work on different files, which are then unavailable to other users. There is transparent data access, allowing everyone to see who is working on what. But there is no instant messaging capability built into the application to communicate requests to free up locked-down files, so collaboration is not as seamless.
Support for Distributed Workflow		✓		A Workgroup Manager is available to set up a collaborative project, define standards for it, manage all the files centrally, and regulate the access rights of who is allowed to make changes to a project. But because files get locked down and unlock requests cannot be communicated instantly, collaboration is not real-time.
Security and Access Controls	✓			Access rights are defined on the basis of layers, by creating “privilege sets” that control access to layers. Individual users can be assigned to one or more privilege sets; users can only see and/or edit the layers that are associated with the privilege set assigned to them.
Performance Across WAN	✓			Individual file sizes are small, so working across a WAN is not an issue, provided sufficient bandwidth is available.
Ability to Handle Large Projects	✓			Since the project is divided into a large number of files, it allows for very large projects to be modeled and to a high level of detail.

Interoperability

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Integration with Structural BIM Applications	✓			Direct integration with Allplan Structure, and close integration with other Allplan structural applications including Allplan Timber, Allplan Reinforced Concrete, Allplan Precast, Nemetschek Scia, and others.
Integration with MEP BIM Applications	✓			Direct integration with Allplan Building Services.
Integration with Sustainable Design Tools	✓			Includes an Energy Module that provides some basic analysis capabilities integrated within the application; additional integration is with applications popular in Europe including ESS, PV*SOL, T*SOL, and AX3000.
Integration with Estimating Applications	✓			Directly integrates with Allplan Building Cost Management and Nemetschek Design2Cost applications.
Integration with Constructability Tools		✓		Includes some integration with Nemetschek's construction tools.
Electronic Publishing and Review		✓		Supports the creation of both 2D and 3D PDF files directly from the application. However, there is no support for DWF.
Range and Quality of Third-Party Tools			✓	Most of the products that integrate with Allplan are Nemetschek products. There is relatively little third-party development.
Number of 3D File Formats Natively Supported		✓		Supports only common 3D file formats including DWG, DXF, DGN, IFC, and PDF. It includes the ability to save different groups of exchange settings as Exchange Favorites, which is helpful. However, the list of supported 3D formats is not as large compared to other BIM applications like Bentley.
Quality of API (Application Programming Interface)	✓			Includes an API called NOI (Nemetschek Object Interface) that is used by 3rd party developers as well as for internal development. In addition, a COM interface is available to support other programming and scripting languages.
IFC Support	✓			Supports the latest version of the IFC format and is a strong advocate of it. (*See Figure 5*)

Implementation

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Initial and Ongoing Pricing/Licensing		✓		More expensive compared to other BIM applications. However, applications can be combined, e.g. Allplan Architecture with Allplan Reinforced Concrete or Allplan Building Systems, without having to pay multiple times for the shared platform functionality.
Initial and Ongoing Training		✓		There is no free training, but it is available as part of consulting services.
Quality of Technical Support		✓		Different forms of support are offered, from support in Internet forums, through hotlines, to training and consulting. Hotline support is free for customers with a software-service contract.
Quality of Included Documentation			✓	Many aspects of the application are not properly described in the documentation, making it difficult to learn the application. The installation CD comes with some movie clips, but these are not very extensive.
Free Online Learning Resources		✓		A new Allplan portal has been set up for students, which has free learning material, video tutorials and a forum to discuss questions, best practices and features. This can also be used by professional users. But apart from this, there are no other learning resources on Allplan's website.
Support Channel (Resellers and Consultants)		✓		Good support channel in Western Europe, and parts of Eastern Europe, Russia, and China, but there are very few resellers in other parts of the world, including the US.
Availability of Trained Staff		✓		It would be easier to find Allplan knowledgeable staff in Europe, but it is practically impossible in the US.

Vendor

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Current Market Position		✓		Allplan is popular in Europe, and is likely to continue being so, given its established user base and the integrated platform benefits it provides to large firms using it.
Long-term Viability	✓			It is the flagship product of Europe's leading AEC software vendor, and is continuing to be developed and improved, so it definitely has long-term viability.
Investment in R&D		✓		The company has expanded its product line considerably and is continuing to add more modules, indicating investment in R&D. However, Allplan still has some archaic features and doesn't seem to be fully up-to-date on BIM yet, indicating that more R&D is needed to improve it.
Responsiveness to Feedback and Requests	✓			There is a dedicated user experience group that collects and analyzes all forms of user feedback. Product management, technical support, consulting, quality assurance, and sales teams also contribute to this. Customer requests, wishes and other feedback are classified, evaluated and incorporated into the product development process.

FIGURE 4. A rendering created within Allplan (top image) versus a rendering of an Allplan project in Cinema 4D (lower image).

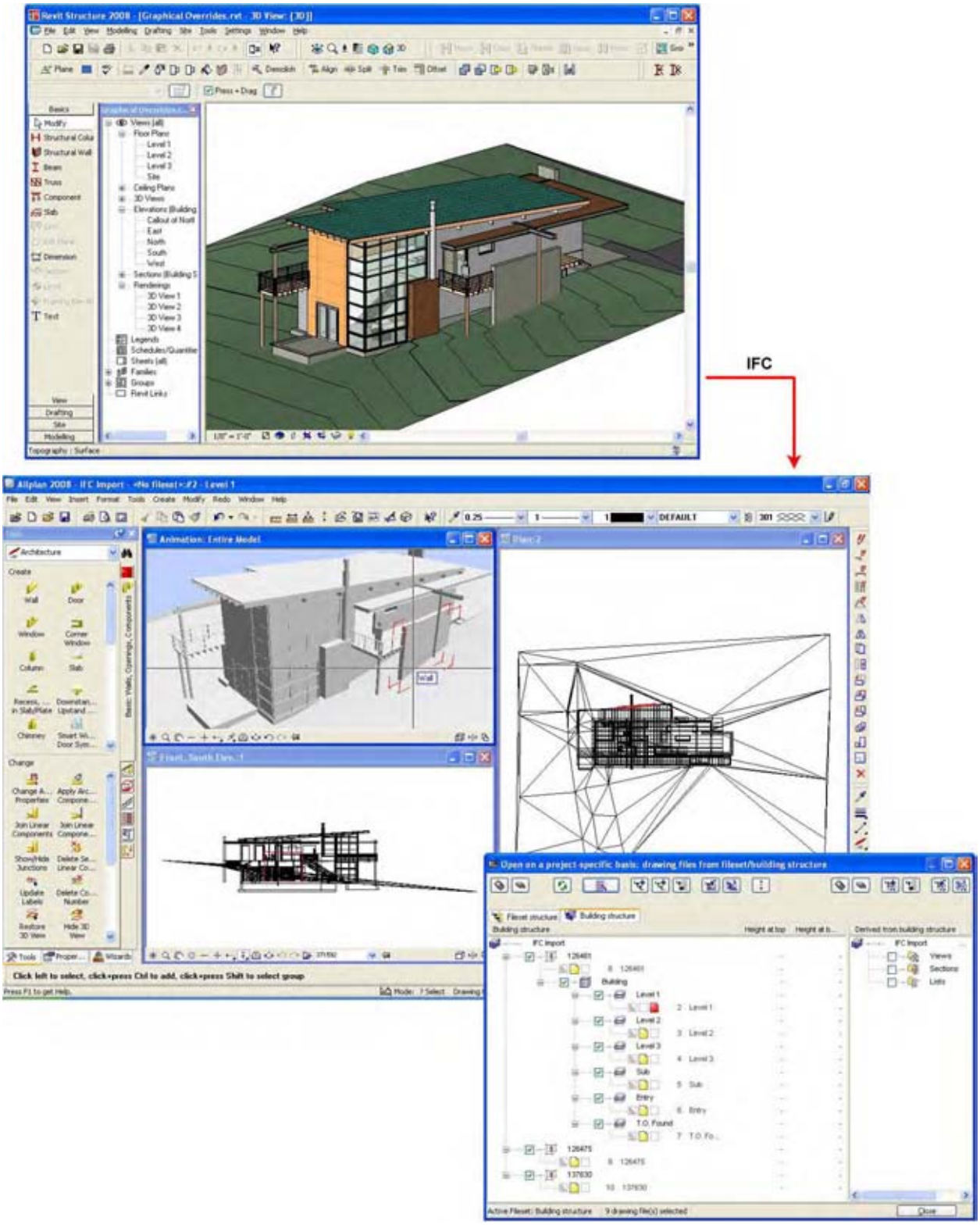


FIGURE 5. Importing an IFC file into Allplan that was exported from Revit. The building structure that was automatically created from the IFC file is also illustrated, showing how the levels were correctly mapped.

DISCUSSION

This section discusses some of the key features of Allplan Architecture in more detail.

Project Setup

Allplan uses a distributed file-based system for BIM, making it similar to Bentley Architecture and Digital Project in this respect. However, it uses a very different approach to setting up a project from either of these applications. A project is the main organizational unit, and it is computationally represented by a folder containing a large number of sub-folders and files. The actual design and data creation process happens in drawing files. A project can contain up to 6,000 drawing files, of which up to 60 files can be displayed and edited simultaneously. Prior to version 2008, the files comprising an Allplan project could only be grouped together into an organizational unit called "fileset." A fileset could have up to 128 drawing files. It was up to the individual user or project administrator to create a fileset structure that mapped to the organization of the building content, and this could be done in many different ways.

In an attempt to make Allplan more "BIM enabled," the 2008 version of Allplan introduced a new organizational mechanism called "building structure" intended to make it easier to create a BIM model. It comes with a plane manager that can be used to define the different levels of the building and their heights. Once this is done, a corresponding building structure is created, as shown in Figure 6-a. The actual modeling continues to happen in separate drawing files, but these are now linked to the building structure and derive the height information from it. So, for example, in Figure 6-a, if you activate a file under the Ground Floor category in the building structure and start placing walls, slabs, columns, etc., the elements will automatically get their elevations and heights from the storey settings associated with the Ground Floor, as shown in Figure 6-b.

To move on to the next level, you would need to activate one of the files associated with that level and start modeling—they will be correctly placed at the right elevation. This is how a model is created, level by level. You can also choose to over-ride the height setting for an element, if, for example, you have an element like a column that needs to span multiple stories. The height settings can be changed at any time, and the model will automatically adjust. So, for example, you could change the height of the ground floor and specify that all the higher levels should be moved up. The model will immediately be updated to reflect this change.

Elements that are not associated with a specific level, for example, an elevator core that extends throughout the height of a building, can be created by activating one of the files directly under the main Building level. The elements modeled in this file will now be floor independent rather than deriving their heights and elevations from a particular level.

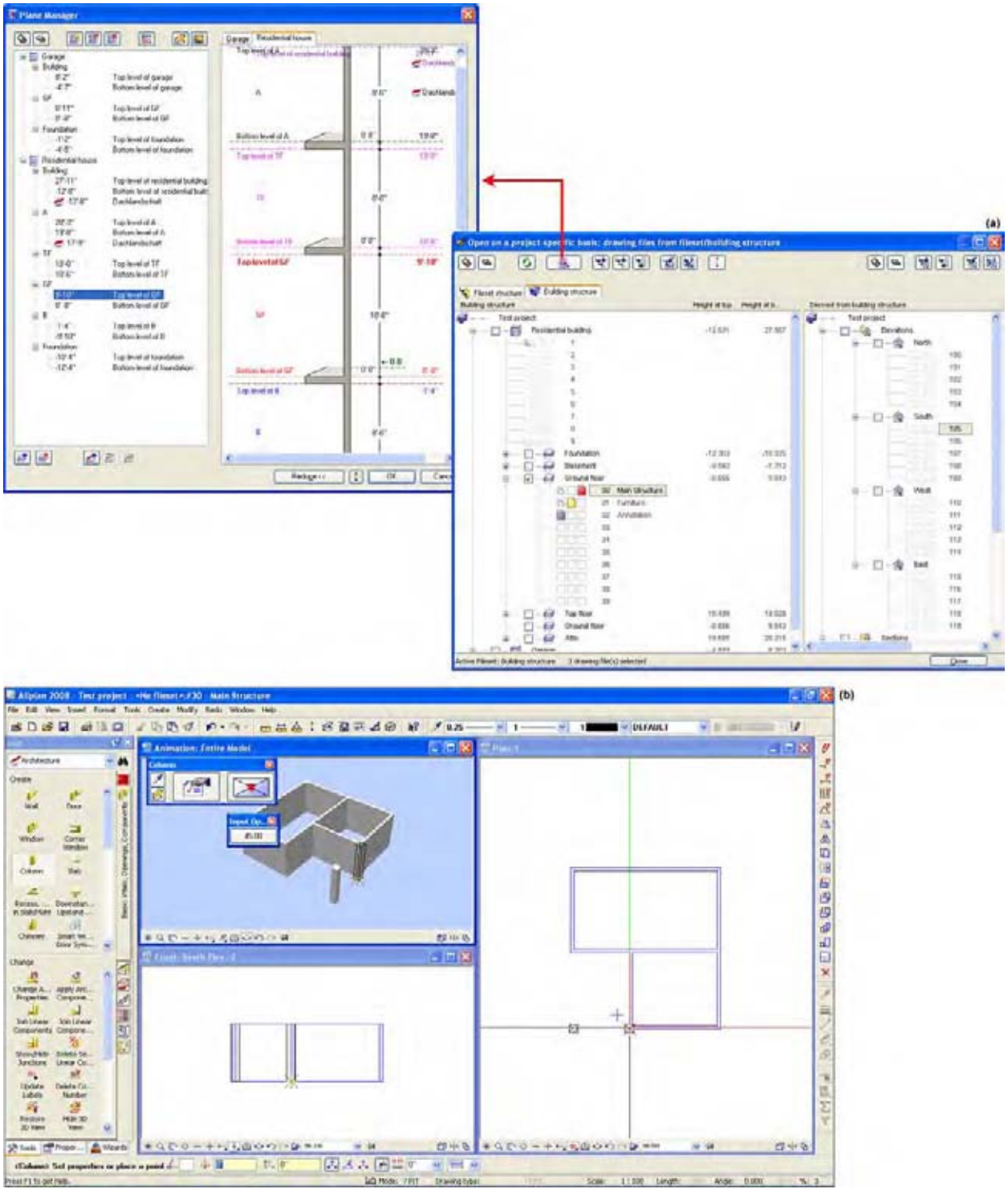


Figure 6. Using the Plane manager to define a building structure with multiple levels, to which individual drawing files are linked.

As shown in Figure 6-a, each level in the building structure can have multiple drawing files associated with it. This allows different elements or groups of objects within a level to be created on different files, if required. So, for example, the structural elements could be created in one file, the walls, doors, and windows in another file, the

furniture layout in a third file, and so on. The building structure contains a number of file assignments for each level by default, but these files are not actually created until they are activated. So, for instance, in the example shown in Figure 6-a, only the file numbers 30, 31, and 32 for the Ground Floor are actually created; the others can be activated if required to create more elements, and additional files can be assigned to this level as well. In addition to activating drawing files (indicated by the red color), the building structure interface can also be used to control whether a file is visible and can be edited (indicated by the yellow color), whether it is in reference mode where it can only be seen but not edited (indicated by the gray color), or if it is not visible at all (no color). This means that multiple files can be opened and edited simultaneously, but any new elements will be created in the active file only.

Elevations, sections, and lists (i.e., schedules) in Allplan are derived from the model using the building structure. As shown in Figure 7, the building structure comes with some predefined elevation, section, and list file assignments. But this does not mean that these views are already predefined and readily available. To create an elevation, for instance, you would first activate a file number in any of the Elevation categories, select the source drawing files containing the elements that need to be included in the view (so the entire model doesn't necessarily need to be included), change the view settings if required, and finally, select the command to actually generate the view. (You can actually choose to generate any elevation type under any Elevation category, so the names such as North, South, etc. in the default building structure are somewhat misleading; however, they can be renamed if required.) Sections and lists are created in a similar fashion. For the sections, of course, the clipping planes have to be defined prior to generating the section.

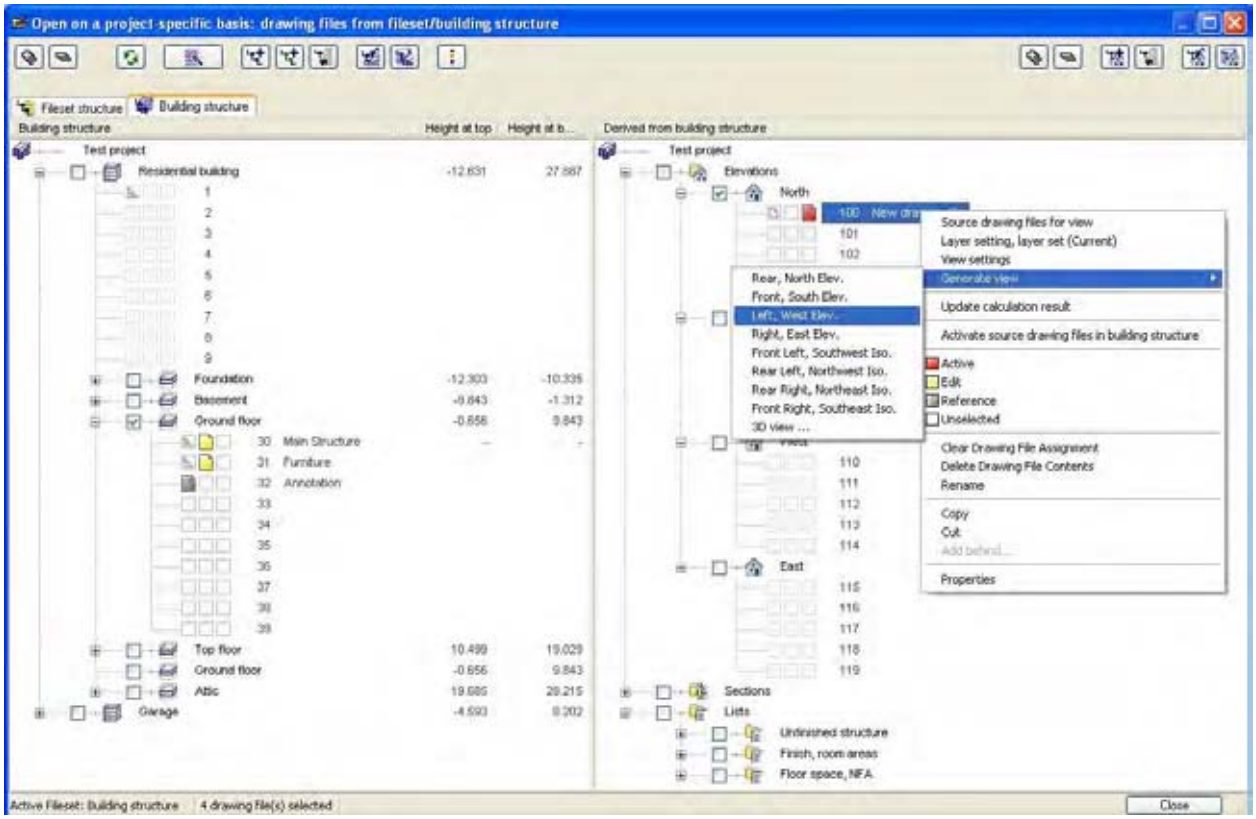


Figure 7. The process of generating an elevation using the building structure interface.

While the project setup can be quite confusing initially, it would actually work far more seamlessly in practice, as firms can set up different building structure templates to use for different project types. The setup might have to be tweaked a little for each new project, but most of the structure would be set up and the individual team members could go in and start working on the individual files right away. All of different components of the building structure shown in Figure 7 could be renamed to suit office and project standards.

Since a project in Allplan can be broken down into as many files as necessary, the collaborative method is very straightforward—users simply work on different files. A Workgroup Manager is available to set up a collaborative project, define standards for it, manage all the files centrally, and regulate the access rights of who is allowed to make changes to a project (see Figure 8). These access rights are defined on the basis of layers, by creating "privilege sets" that control access to layers. Individual users can be assigned to one or more privilege sets; users can only see and/or edit the layers that are associated with the privilege set assigned to them. The Workgroup Manager ensures that when a user is working on a file or a set of files, it is locked down and cannot be edited by another user. Users can access the project independent of location and there is transparent data access, allowing everyone to see who is working on what. A multi-file system data maintenance capability allows several files to be loaded and unloaded simultaneously.

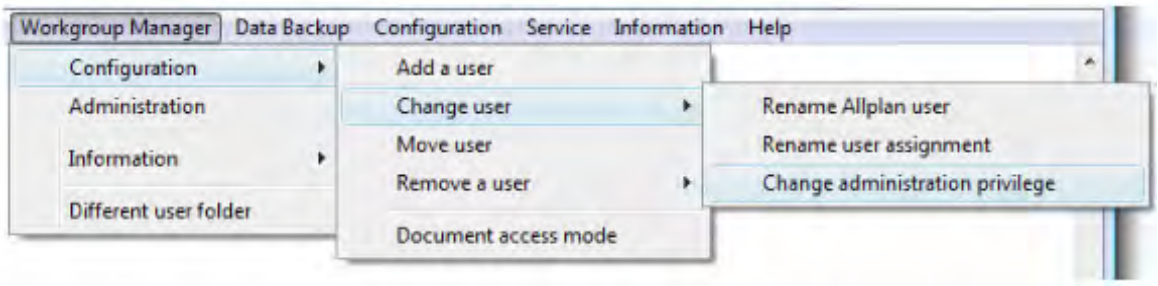


Figure 8. The Workgroup Manager interface in Allplan.

Since the collaborative capability in Allplan is based on multiple files, similar to Bentley Architecture, it shares the same limitations of not enabling real-time collaboration. Users cannot work with a file that has been locked down by another user, even though the other user may not be actually working on it at that time. There is no messaging capability built into the application to communicate requests to free up locked-down files. Another serious limitation in Allplan related to the file-based approach is that views such as elevations and sections derived from the model are not automatically updated when the model is changed—they have to be recalculated to show the changes. Thus, there is no "dynamic views" capability that Bentley has managed to achieve despite having the same distributed file approach. However, Allplan's ability to enable a project to have up to 6,000 different files gives it the capability to handle very large projects by extended design teams. This has been the key strength of the application and the main reason why it has been widely adopted by large firms in Europe for many years.

Interface

Allplan has a very large toolset with an extended set of options for every tool, giving it an extensive repertoire of capabilities. Yet its interface has been designed in such a way that the tools themselves are not particularly overwhelming. They are nicely organized in tool palettes categorized by function and module, which makes them easy to find and use. Tool dialogs are well designed so that even with the extensive number of options, they are clear and can be understood without constantly referring to the documentation. Wizards are available for many

common tasks. You can quickly create an element by selecting a similar element that is already created, which can be extremely efficient. The interface allows the model to be created and edited in multiple viewpoints, so that you can start an operation in a plan view and seamlessly move on to an elevation, section, or 3D view to continue it. Also, it is possible to work completely in full screen mode with no open tool palettes and dialogs, summoning the required tool when needed by using a shortcut key or mouse click. This is extremely helpful for advanced users of the application and can allow them to work with great speed and efficiency.

One key deficiency, however, in Allplan is the lack of associativity between building elements, which makes modeling and editing longer and more involved. Just as with ArchiCAD, even basic wall connectivity is missing. So, for instance, if you move a wall using the Move tool, the walls connected to it do not automatically adjust to maintain the connectivity and the room element too does not automatically fill out to the new boundary. While a Stretch Entities tool is available to make these kinds of simultaneous modifications, it is somewhat tedious to use and is based on geometry rather than on understanding and maintaining the relationships between building elements. Therefore, it cannot fully make up for the lack of associativity.

There are some other limitations as well which hamper intuitiveness and ease of use. For instance, there is no direct way to open projects that you receive from others, as the Open Project command does not let you browse to any folder located on your computer. You have to open up a separate application, set a backup path to the location where the project is stored, and then run an Import command; only then can you go and open this as a new project in Allplan. The documentation is quite poor at explaining this and many other basic concepts, and there are no tutorials that can walk you through the process of getting started with the application. Consequently, it takes a long time to fully understand how the application works.

Functionality

The core functionality of Allplan Architecture is similar to other BIM applications for architectural design: you create a building model using intelligent parametric components, and you can then generate all your other deliverables from it, including drawings, renderings, animations, schedules, and so on. In addition, because of its ability to be integrated with Allplan's cost estimating solutions, Allplan Architecture has advanced quantity take-off capabilities, with the ability to precisely calculate quantities, generate lists and schedules, or transfer data to systems used for tendering, ordering and billing. Each of the individual building elements that can be modeled in the application has several attributes that capture its properties in detail to make quantity take-off more exact and precise.

The range of tools for creating different kinds of building components is extensive. For example, there are dedicated tools for creating regular walls, profile walls, and freeform walls. Each individual tool is very sophisticated and comes with a wide variety of modeling options. Take the regular Wall tool, for instance. Clicking on it opens up the context toolbar shown in Figure 9-a, where you can start by choosing the type of wall geometry. If you select the Rectangular option, you can further choose from a set of four different input options which allow you to model the rectangular wall enclosure in varied ways. You can also use the Properties button on the Wall toolbar to access the dialog where you can specify the properties of the wall in great detail, including the number of construction layers and the attributes and materials of each layer (see Figure 9-b). An additional Height dialog, accessible from the Properties dialog, allows you to define the height of the wall, or in the case of walls with multiple layers, the height of the first layer (see Figure 9-c). The height can be defined as an absolute value, or can be associated with default or custom reference planes, or specified relative to other building elements. There are also several additional parameters and attributes for the wall layers that can be defined, such as thickness, material,

display properties in both 2D and 3D, as well as costing-related information such as the Trade category and an associated code. All of these properties can be defined prior to creating a wall, or can be fine-tuned at any time after the wall has been created.

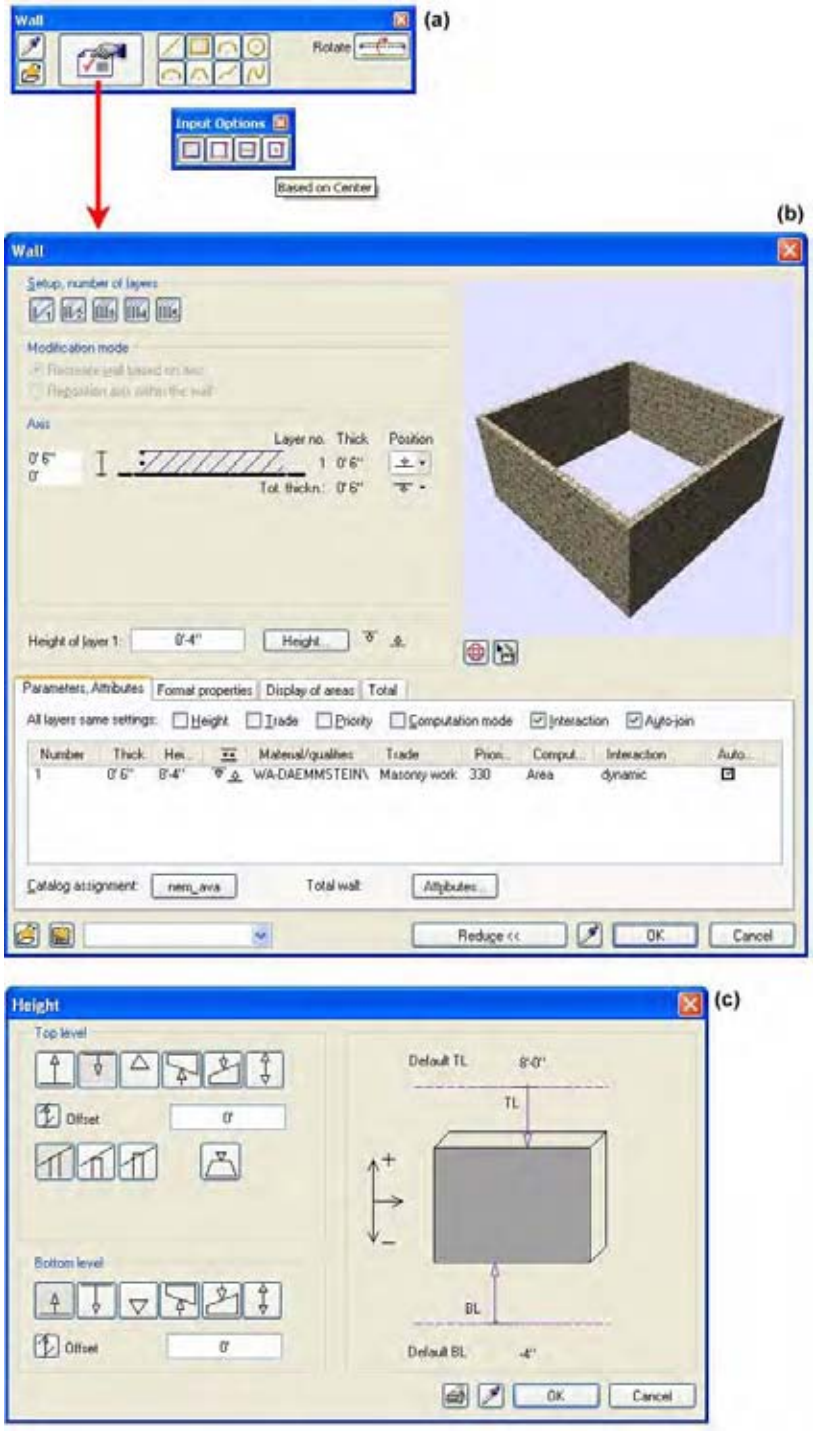


FIGURE 9. The wide range of options and settings for creating a wall in Allplan Architecture.

The Windows tool is another good example of the extensive range of modeling options that Allplan provides. Selecting this tool opens up the context toolbar shown in Figure 10-a. You can change the anchor point for the window placement to the midpoint or either one of the endpoints, based on the specific modeling situation. Another useful option is "Enquire width of opening" which, when checked, displays the offset distance between the point on the wall that is clicked and the nearest reference point and allows this value to be changed, so that the opening can be defined more precisely. The actual properties of the window opening can be specified in the accompanying Properties dialog, shown in Figure 10-b. As you can see, you are not limited to just rectangular opening shapes but can choose from among six different options. Even more impressive is the fact that the window element type that you select (see the Smart Symbol section in the lower left corner of the dialog), will automatically adjust based on the shape of the window opening that has been chosen. Figure 10-c shows the same window element automatically configured for four different opening shapes on the same wall. And just as with walls, changes to the window shape and element can be made at any time after the window has been created.

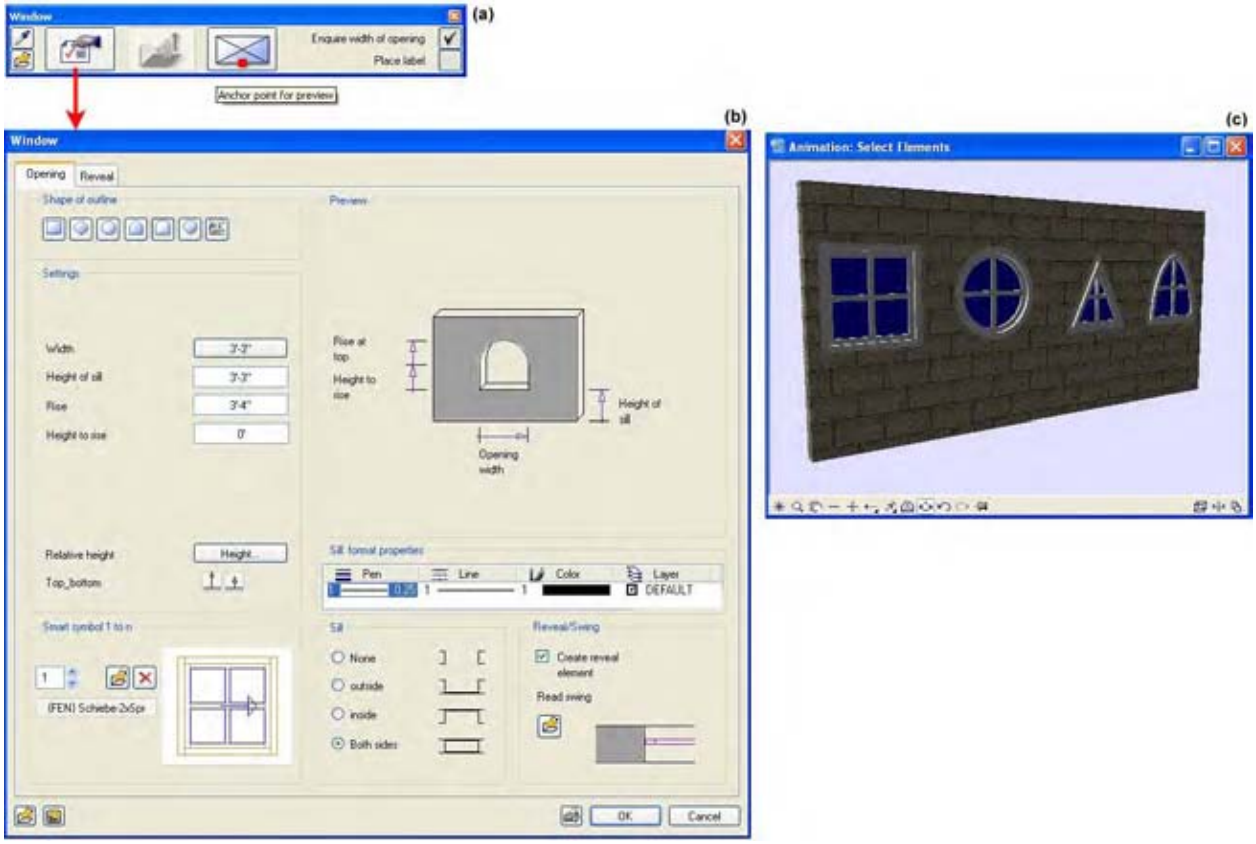


FIGURE 10. The Window toolbar and Properties dialog showing the extensive modeling options, along with some examples of window openings of different shapes that can be created by using the same window element.

Similar to walls and windows, Allplan includes tools for creating a wide variety of building objects including doors, columns, beams, slabs, corner windows, chimneys, railings, and different kinds of foundations, as well as detailed components such as upstands, lintels, window sills, joints, rabbets, facings, roller blind housing, installation masonry, and so on. There is a whole suite of tools for the parametric design of different stair types, as well as a large toolset for the design of all roof types including pitched roof, gambrel roof, barrel roof, dormers and more complex roof designs with skylights. Room elements can be created or placed inside spatial enclosures and

associated with an extensive list of attributes, which can be used to create color-filled plans based on various criteria for space planning and facilities management.

Special mention must be made of the new Façade tool that lets you create facades (i.e., curtain walls) in different ways: along paths that can combine lines and curves and be vertical or inclined; area facades created by simply drawing out the façade surface anywhere in 3D space; converting any 3D geometrical form into a façade (in a manner somewhat similar to Revit's BuildingMaker). Some examples are shown in Figure 11. The individual elements of the façade can be completely customized, including the pattern and types of openings; in addition, there are several predefined "façade favorites" to design the most common facades. You can also quickly place a façade inside any existing opening of any shape. The power and sophistication of the Façade tool in Allplan Architecture is very impressive and is far better than the curtain wall modeling capabilities provided by any of the other BIM applications.

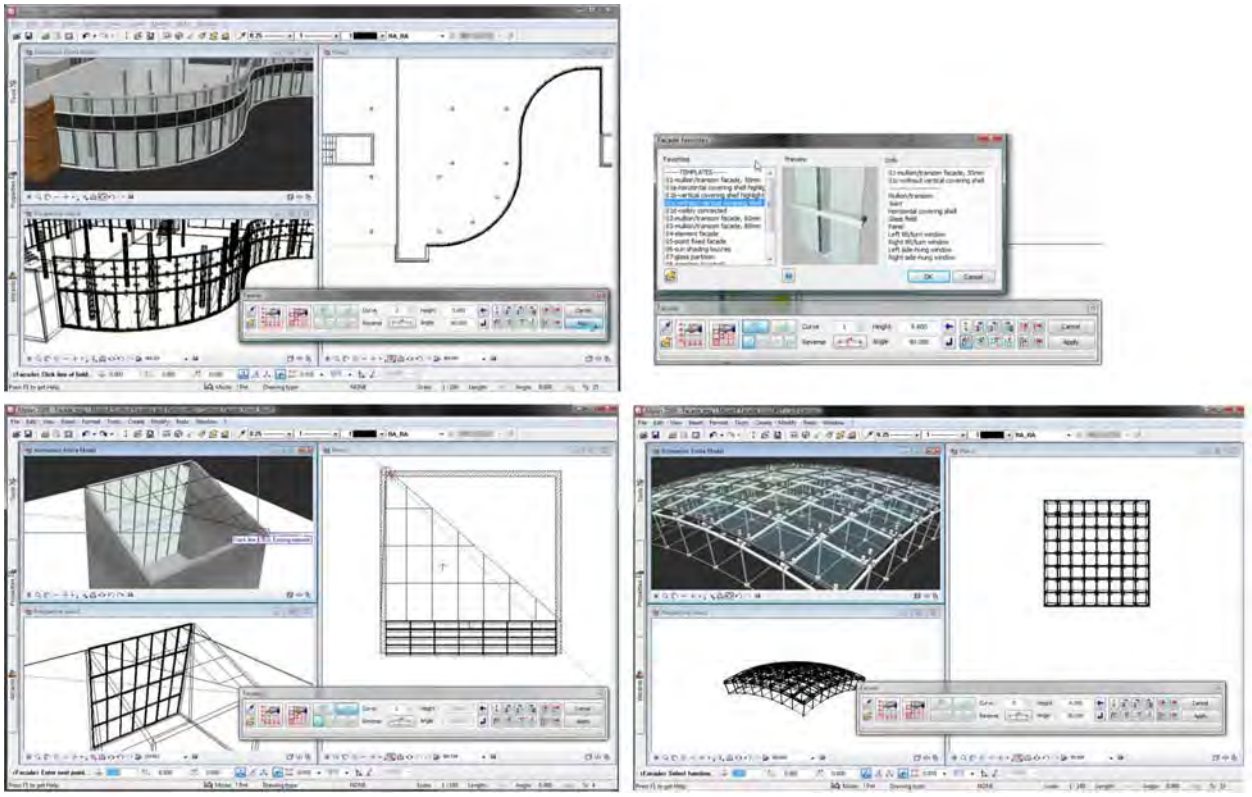


FIGURE 11. The Powerful Façade tool in Allplan Architecture allows complex facades to be quickly created in different ways.

In addition to object-oriented building modeling tools, Allplan includes a full array of modeling tools for creating standard solids, solids of revolution, sweep solids, pyramids, tessellated solids, and other solid types, as well as the use of Boolean operators for combining or subtracting solids. This allows the model to easily include freeform shapes that the standard BIM tools cannot create, such as those shown in Figure 12-a. A Geo module provides the full gamut of tools for site plan design, terrain modeling, landscaping, urban planning, and cadastral plans, with the ability for slope calculations, cut and fill, longitudinal sections, curved lines, torsion lines, profiles, quantities, etc. (see Figure 12-b). This allows civil engineers to work on the site design using the same application as the architects, enabling both disciplines to better integrate their work and collaborate with each other.

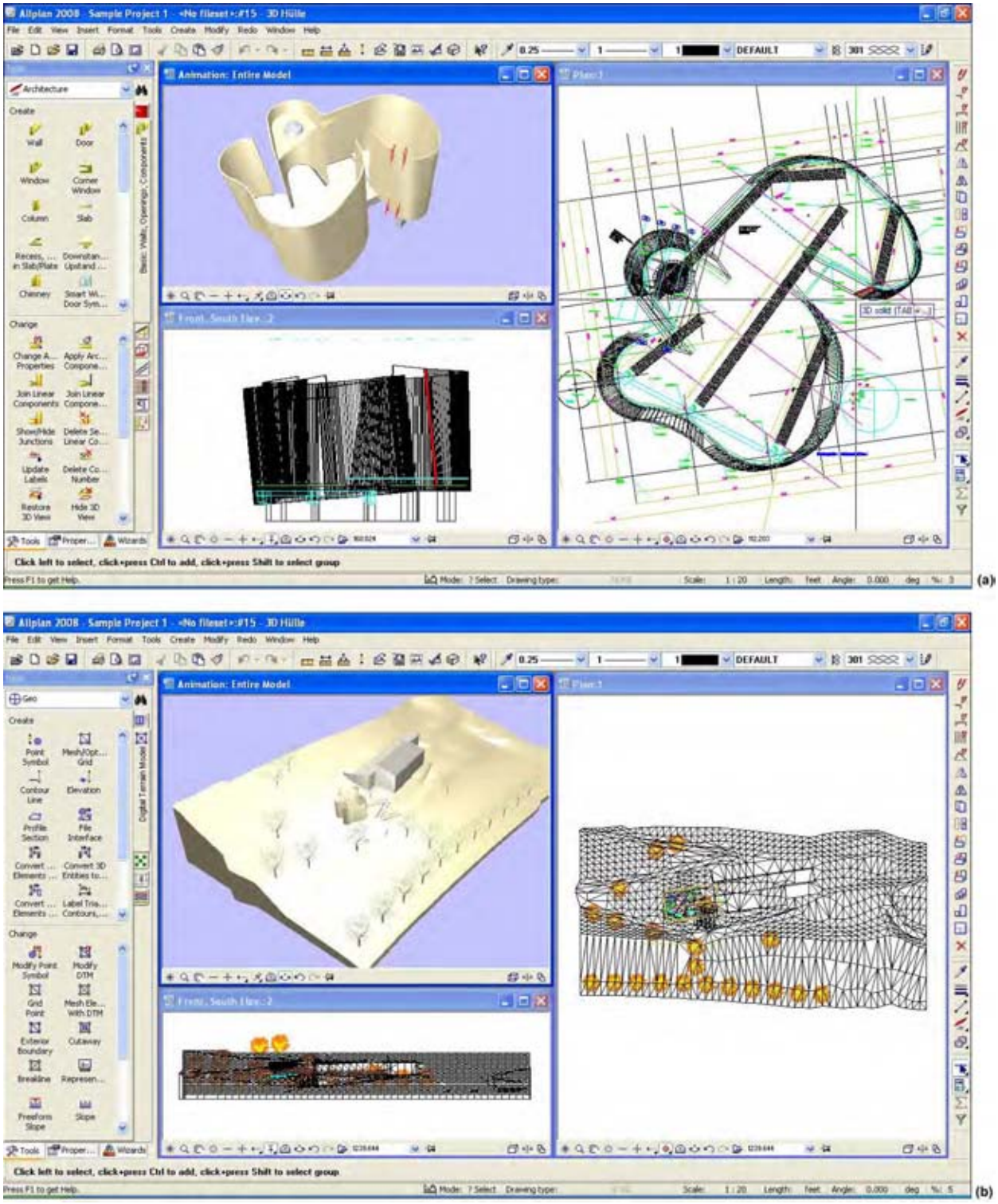


FIGURE 12. A sample project showing the creation of freeform shapes in the model as well as a sloping site created using the terrain modeling tools.

Rounding off the capabilities of the application are tools for annotating and dimensioning; a Layout Editor for creating layouts (that is, sheets) that combine drawings, images, graphics and text; a freehand sketching module for conceptual sketching and red-lining; an extensive library of catalogs with 2D symbols and 3D objects, material definitions, textures, and so on; the ability to calculate shadows from multiple light sources and create sun studies that can be saved as animations; built in tools that allow photorealistic images to be created using various rendering methods, along with an interactive connection to Cinema 4D for more sophisticated renderings; and the ability to create walk-throughs that can be saved as AVI movies.

CONCLUSION

Allplan is a very powerful and flexible application that has top-of-the-line modeling capabilities. The sheer number of tools and each of their individual options gives it one of the most extensive repertoire of capabilities that is currently available in a BIM application, both in breadth and in depth. And yet, its interface has been designed in such a way that it is not too overwhelming. Since it has the full gamut of 3D modeling tools in addition to its building object modeling tools, it does not constrain the building design in any way. The forms that cannot be modeled with the building tools can be easily modeled with the other tools or imported from other applications. Other pluses are its multi-disciplinary capability, all available within the same application, the large number of additional modules that extend its capabilities, and the ability to directly integrate with Allplan's cost estimating solutions, enabling accurate determination of building quantities and costs without the need to re-create the model in another application. The distributed file structure enables it to handle large projects easily and support a distributed project team; however, the collaboration is not flexible and real-time as it is in ArchiCAD.

On the flip side, just as with the Bentley BIM solutions, the distributed approach does come with its share of complexity and non-intuitiveness of use. The manner in which the project is set up in Allplan is completely different from any other application and takes time to understand and get used to. In time, hopefully the project structure can be revamped to make it more user-friendly, so that the user can go ahead and model without having to worry about which file to activate, and views such as elevations and sections are immediately available without having to undertake a whole sequence of steps to generate them. Elevations and sections also need to be capable of updating automatically when the model is changed—these have become, by now, standard expectations from a BIM application. Also, the layer-based "privilege sets" to control access in a distributed team project in Allplan seems quite archaic, given that layers are mostly associated with CAD applications rather than BIM. The lack of associativity between building elements in its modeling interface is another serious limitation that makes the application seem not as "smart" as other applications that have this capability. If Allplan can properly address these limitations, there is a good chance that it can emerge as a viable BIM contender outside of its established base in Europe, given the long history of the application and the sophistication of its modeling tools that have evolved over the course of many years.

Vectorworks Architect

Vectorworks Architect is developed by Nemetschek North America Inc., a subsidiary of the Germany-based Nemetschek AG, which is the developer of Allplan and also owns ArchiCAD after its 2007 acquisition of Graphisoft. NNA started in the mid-1980s as Diehl Graphisoft, Inc. which developed MiniCAD, one of the first CAD and 3D modeling applications. MiniCAD was also the first cross-platform CAD application, working on both Macs and PCs, and was therefore quite popular, as the Mac was the leading computer used by designers at that time.

Diehl Graphisoft merged with Nemetschek AG in 2000 and became Nemetschek North America (NNA), Nemetschek's largest U.S. subsidiary. MiniCAD was renamed as Vectorworks and in addition to the core 2D drafting and 3D modeling platform called Vectorworks Fundamentals, the product family has been expanded to include several additional modules. These include Architect for building design; Landmark for landscape and site design; Machine Design for product designers, machine shops, and metal fabricators; and Spotlight for entertainment design (auditoriums, video screens, seating layout, lighting devices, etc.), scene and set design, and event planning. A Designer product that combines all of the above modules into one comprehensive program is available for those who need it. The product family also includes Renderworks, a dedicated rendering and presentation module that work with all Vectorworks products.

NNA has always positioned Vectorworks as a low-cost CAD alternative, and it adopted the same approach with Vectorworks Architect, positioning it as a cost-effective BIM alternative for those firms and architects who are holding back from BIM implementation because of the cost. The company was actually quite late in getting on the BIM bandwagon, and was still pitching the application as "CAD for the Smart-Sized Firm" even in 2005, when the BIM revolution was well underway. It started referring to Vectorworks Architect as a BIM application only in 2006 when version 12 of the application was released. Even after that, it took a while for the AEC industry to acknowledge it as a BIM application. For example, Vectorworks Architect was not discussed at all in "The BIM Handbook," the highly respected book on BIM authored by leading academics and researchers such as Chuck Eastman and Paul Teicholz, a fact that I noted in my review of the book and which was also the subject of some discussion on the AECbytes blog.

In the last couple of years, however, NNA has made rapid progress in transforming Vectorworks Architect from a CAD to a BIM application and improving its usability. While it is not yet as powerful or comprehensive as the other BIM applications reviewed in this study, it is entirely possible to create a BIM model of even a large project in Vectorworks Architect. The model can be created in a single file, or divided up into smaller files that can then be assembled into the full model using a referencing capability. The latter approach would be adopted for a distributed design team. While Vectorworks Architect does not have any multi-disciplinary capability, it includes IFC support and can thus be used as part of a multi-disciplinary workflow. The application's interface is a little quirky and not as sophisticated as the other BIM applications, and its underlying drawing-centric nature is still very much in evidence. But once it has been understood and mastered, it can work as a perfectly functional BIM application. Available at less than half the cost of the other BIM applications, it is also good value for money. With much of the BIM usage currently limited to the larger firms, NNA is continuing to target Vectorworks Architect towards smaller firms that are having trouble moving to BIM, with the promise of enabling them to make the change without too much upheaval. It has a fully developed CAD toolset and allows users to revert back to using it as a 2D CAD application at any time—it does not mandate the use of BIM. I anticipate that NNA will continue with this "hybrid" CAD/BIM approach and at the same time, continue developing the BIM capabilities of the application to better prepare it for the not too distant future when BIM becomes the norm for the building industry.

EVALUATION SUMMARY

Key Strengths

- Very cost-effective, with a price that is less than half of other BIM applications
- Comes with an inexpensive Renderworks plug-in that can be used to generate high-quality renderings
- Includes a Parasolid modeling engine that provide faster and improved 3D modeling capabilities
- Organic forms can be modeled with the extensive 3D modeling toolset and assigned meaningful building-related IFC data
- Has added several BIM-related enhancements in the last few releases
- Includes site modeling tools with cut and fill calculations
- Includes tools for space planning and programming
- Strongly committed to interoperability and IFC support
- Includes several customization capabilities including a lightweight scripting language as well as a more extensive and sophisticated C++ based API
- Good quality of built-in documentation and online resources, including sample files and video tutorials
- Cross-platform (Windows and Mac)

Main Limitations

- Does not directly integrate with any structural or MEP engineering tools
- Has a hybrid 2D/3D design environment that is more CAD-like than BIM-like
- Interface is somewhat quirky and not fully updated for 3D
- Content library and automation of tasks such as wall and roof framing are geared primarily towards residential design
- Inadequate modeling capabilities for some critical building elements such as floors, curtain walls, beams, and other structural elements
- Project setup for BIM is cumbersome and confusing with too many constructs
- Does not provide any specific support for large projects, model collaboration, or distributed workflows
- Was late to develop BIM capabilities, so it is not widely considered or used as a BIM application

Price

Full price for the first license and 20% discount on additional seats. Full prices for different configurations are given below.

- Vectorworks Architect: $1,995
- Vectorworks Architect with Renderworks: $2,395
- Vectorworks Designer with Renderworks (includes Architect, Landmark, Spotlight, Machine Design): $2,895

DETAILED EVALUATION

Application Repertoire

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Space Planning/ Programming	✓			Includes a suite of tools for space planning and programming studies, including bubble diagrams, adjacency matrix, space links with scores, and stacking diagrams for multiple floors. Subsequently, the spaces can be automatically converted to walls. (*See Figure 1*)
Conceptual Design/ Mass Modeling		✓		Includes a fairly extensive 3D modeling toolset including primitive solids, extrusions, surfaces of rotation, sweeps, NURBS curves and surfaces, constructive solid geometry (boolean operations) and others. However, the modeling interface is somewhat quirky and not as easy and intuitive as tools like SketchUp.
Detailed Modeling		✓		Tools are available to model all the basic building elements, including walls, doors, windows, stairs, roofs, and so on, along with MEP elements and detailed site modeling tools. But some tools are quite rudimentary, such as floors and curtain walls.
Schedules and Reporting	✓			Any collection of attributes, properties, and dimensional characteristics of the model elements can be displayed in a schedule or worksheet. It is bi-directional, so that changes to the worksheet also update the corresponding elements in the model.
Quantity Take-off		✓		There are no built-in quantity take-off tools, but the worksheet capability works like Excel and includes many numerical functions including area and volume calculations, allowing it to be used to extract model data and perform calculations on it to create material lists.
Photorealistic Renderings	✓			A Renderworks plug-in module is available that allows high-quality photorealistic renderings to be generated within Vectorworks. It supports ray-tracing, radiosity-based illumination, intuitive texture mapping controls, 3D entourage, support for High Dynamic Range Images (HDRI), and other features. (*See Figure 2*)
Animations		✓		The Renderworks plug-in allows three different types of animations to be created: standard fly-overs about a point in space; walk-throughs with a moving camera; and daylong solar/shadow study for a given location and day of the year. However, there is no dedicated set of animation tools such as keyframes, timeline and velocity graphs, etc.
Real-time Model Exploration			✓	Real-time fly-overs and perspective walk-throughs are only available in wireframe or OpenGL display modes.

Construction Documents	✓			Drawings can be generated from the model. Includes full set of drawing, dimensioning, and annotation tools, including a database-driven callout and general notes capability and automatic coordination of drawing references. (*See Figure 3*)
Coordination/ Clash detection			✓	No internal coordination or clash detection capability with other disciplinary models. Relies on IFC export and external applications such as Navisworks and Solibri Model Checker.
Fabrication		✓		3D solids can be exported to any other Parasolid-kernel-based applications such as SolidWorks using the X_T file format, enabling them to be used for manufacturing and mechanical design.

Intrinsic Nature and Capabilities

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Intuitiveness and Ease of Use		✓		While the overall interface is relatively easy to navigate and use, parts of it are primitive and quirky.
Ease of Project Setup		✓		Most of the project setup is related to the CAD functionality (layer names, layer scale, drawing display and dimensions, sheets and title blocks, etc). Model setup including building levels and different views (plans, elevations, sections, 3D, etc.) is not as intuitive.
Information Re-Use		✓		Some level of information re-use is supported: for example, space plan can be used to derive walls, generic elements can be replaced with more specific elements while maintaining critical alignments, etc. But massing model cannot be converted to building model, floors can't be derived from wall enclosures or spaces, and so on.
Modeling of Organic Building Forms	✓			Organic forms can be modeled with the extensive 3D modeling toolset and assigned meaningful building-related IFC data. (*See Figure 4*)
Automation of Tasks		✓		Includes automated roof framing, floor framing, wall framing and panelization capabilities, and parametric, fully configurable stairs. In addition, scripts can be written to automate repetitive tasks. (*See Figures 5 and 6*)
Creation of Parametric Forms			✓	While the application comes with some parametric content such as doors, windows, ramps, elevators, etc., and custom content can be created within the application, there is no interface for creating custom parametric content or forms driven by parameters.
Associative Behavior of Building Elements		✓		Includes some built-in object associations such as wall to wall, and space to wall. In addition, it has the ability to specify some dimensional relationships and constraints, for example, constraining a wall to be horizontal, constraining a hallway to be of a certain width, etc.

Guarantee of Model Integrity			✓	There is no check for model integrity. Physically impossible situations such as overlapping doors can be easily created.
Availability of BIM Content		✓		Ships with a fairly good collection of architectural BIM content that has embedded IFC data for competent export to other applications. However, there is little third party development of BIM content for this application; it is mostly developed in-house by NNA.
Customization Capability	✓			Includes several customization capabilities: a lightweight scripting language called VectorScript, a more extensive and sophisticated a C++ based API, as well as several commands that provide ways for the non-programming user to automatically generate human-readable scripts that can then be easily modified as required.
Support for 3D Printing	✓			Exports 3D STL (Stereo Lithography) format.
Multi-Processing Support		✓		All of the Parasolid-based functionality in Vectorworks takes advantage of multiprocessing, but only on the Macintosh.
64-bit OS Support			✓	The application is only 32-bit at this time.
Cross-Platform (Windows, Mac)	✓			Runs on Windows XP, Windows Vista, and Mac OS.

Issues Specific to Large Firms

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Model Performance		✓		File sizes for projects typically range from 20 MB to over 110 MB. Larger projects are broken up into smaller files to improve performance.
Model Sharing Technology			✓	There is no model-sharing technology apart from the ability to combine any number of files into a unified project file through referencing. Collaboration requires communicating by voice or email as the model alone cannot be used for collaboration.
Support for Distributed Workflow			✓	The project can be broken up into multiple files, and one user can work on one file at a time. Changes to other files cannot be seen in real time; references have to be updated to see the changes. There are no specific set of tools to simplify the workflow for distributed teams.
Security and Access Controls			✓	Since the collaboration is file-based, it relies on the access-privileges provided by the computer or network operating system.
Performance Across WAN		✓		Since the model-sharing is not real-time but is updated on command, a high bandwidth WAN provides adequate support for the exchange of model information.
Ability to Handle Large Projects		✓		Large projects are handled by breaking them up into smaller files.

Interoperability

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Integration with Structural BIM Applications			✓	No direct integration with established structural BIM applications; relies on IFC for collaborative, multi-disciplinary work.
Integration with MEP BIM Applications			✓	No direct integration with established MEP BIM applications; relies on IFC for collaborative, multi-disciplinary work.
Integration with Sustainable Design Tools			✓	No direct integration with any third-party energy analysis tools; worksheets can be used to derive data for energy analysis.
Integration with Estimating Applications			✓	No direct integration with established cost estimating applications; worksheets can be used for quantity take-off to input to estimating applications.
Integration with Constructability Tools		✓		Integrates with InteriorCAD for millwork design and CAM production, and Vectorworks Machine Design for machine design and mechanical components.
Electronic Publishing and Review		✓		Supports full fidelity, snappable PDF files and multi-layer and/or multi-page PDF output for review and markup through integration of Adobe PDF libraries. However, this is limited to 2D PDFs; there is no support for 3D PDF or DWF for model sharing and review.
Range and Quality of Third-Party Tools			✓	Main third-party tool development limited to InteriorCAD (for millwork design), and Land Planning for Vectorworks (for land planning and subdivision layout). Other small third-party tools do exist such as VectorPlugins (vectorplugins.com), VectorBits (vectorbits.com), and VectorDepot (vectordepot.com), but these are focused primarily on Vectorworks' 2D CAD functionality.
Number of 3D File Formats Natively Supported	✓			Imports and exports a wide range of file formats including DWG/DXF, IFC, IGES, 3DS, SAT, Parasolid_XT; exports KML files for Google Earth; imports SketchUp files.
Quality of API (Application Programming Interface)	✓			Includes a full-fledged C++ based API (Application Programming Interface) that provides access to data structures, debugging tools, and operating system infrastructure. It can also be used to create parametric architectural objects. It requires a higher level of programming experience and expertise.
IFC Support	✓			Strong proponent of the IFC standard. Relies heavily on the IFC file format for exchanging data with other applications, since it lacks a multi-disciplinary BIM suite of applications.

Implementation

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Initial and Ongoing Pricing/Licensing	✓			Pricing and licensing options for Vectorworks are very competitive. Professional licenses are sold on a per seat basis, with a full price purchase for the first license and 20% discount on additional seats.
Initial and Ongoing Training		✓		Provides reasonably priced onsite training ($1,650 per day), 2-day classroom training ($750), or one-on-one Internet-based training ($100 per hour).
Quality of Technical Support	✓			Technical support for the US is provided for free to any user maintaining an active license of one of the two most recent versions. Telephone and email support is offered as part of this free service. A Premium support option is available for firms who wish to have priority placement in the support queue, which costs $75 per year.
Quality of Included Documentation	✓			In addition to Help documentation, the installation CD comes with tutorials, exercise files, and videos showing the new features of the application.
Free Online Learning Resources	✓			Sample files of actual projects are available online and can be downloaded to work with; lots of video tutorials available online to learn about different aspects of the program.
Support Channel (Resellers and Consultants)		✓		Includes authorized distributors in close to 70 countries around the world, but not that many independent consultants apart from the distributors.
Availability of Trained Staff			✓	Schools receive favorable pricing and network licensing options, and students are eligible to receive a free copy of Vectorworks. However, the application is not widely used as a BIM application, so finding trained staff is not easy.

Vendor

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Current Market Position			✓	Popular among smaller architectural firms but trailing behind other applications in BIM implementation.
Long-term Viability		✓		Can maintain its niche as a low-cost, hybrid 2D-3D BIM application until the industry fully transitions to BIM.
Investment in R&D		✓		Product engineering and marketing personnel actively go out into the field to observe workflows and identify areas for future development.
Responsiveness to Feedback and Requests	✓			Very active in responding to feedback and feature requests. Users can get responses directly from decision makers at the company. A formal wish list and quality assurance system are available that end users are encouraged to use at nemetschek.net/support/bugsubmit.php. This information is monitored closely and used in product development.

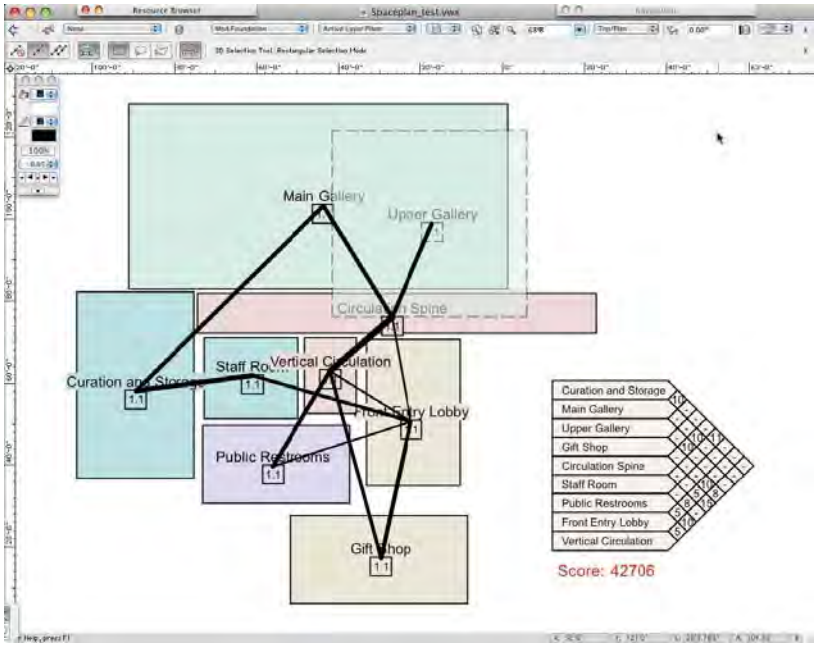


FIGURE 1. Space planning tools in Vectorworks Architect.

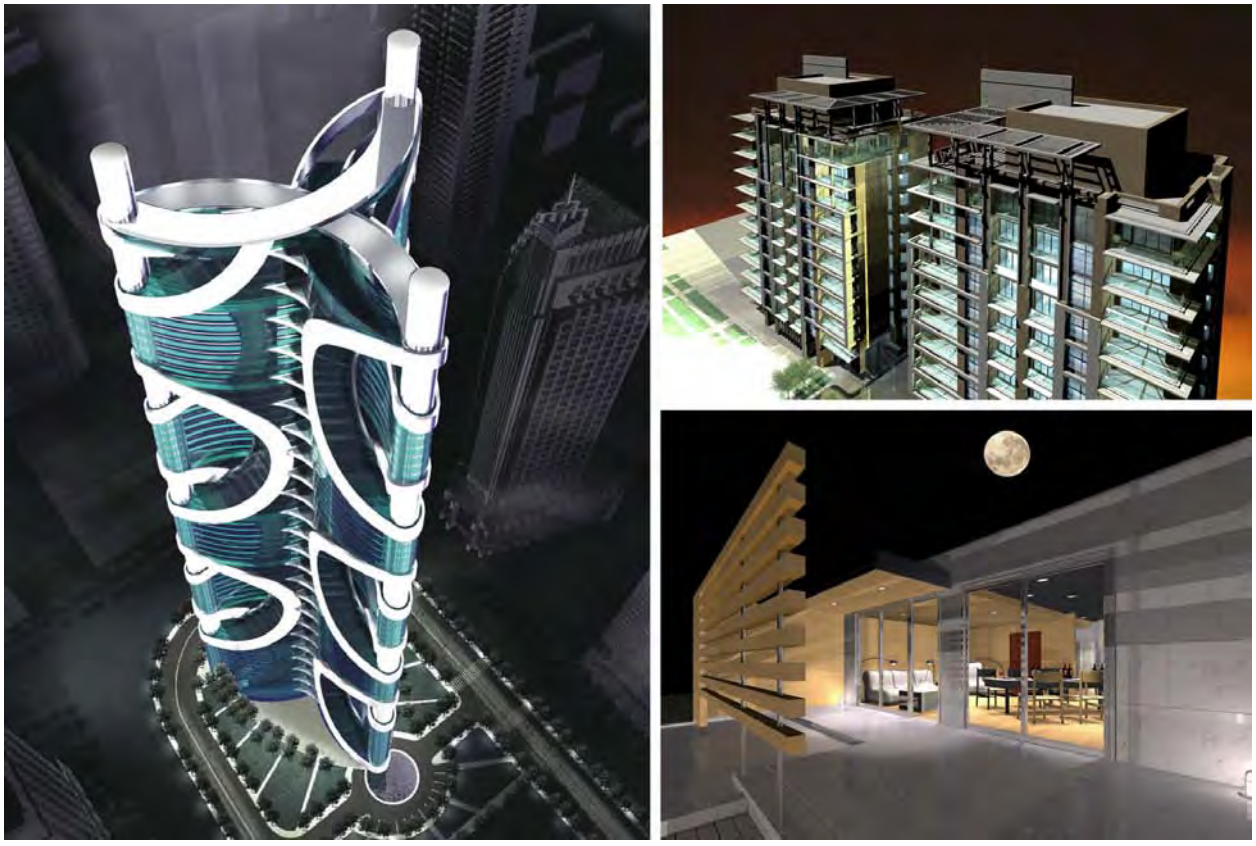


FIGURE 2. Examples of renderings created using Vectorworks Architect with the Renderworks plugin.

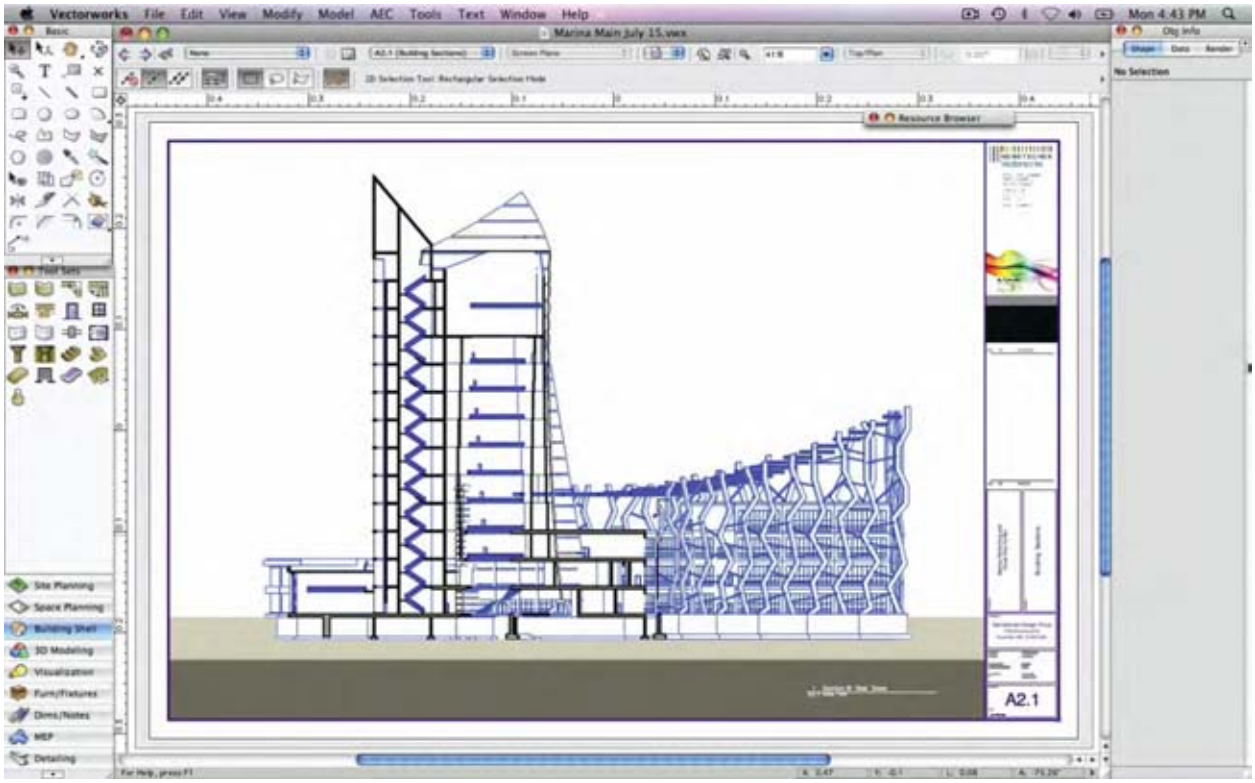


FIGURE 3. Example of a 2D drawing generated from a building model in Vectorworks Architect.

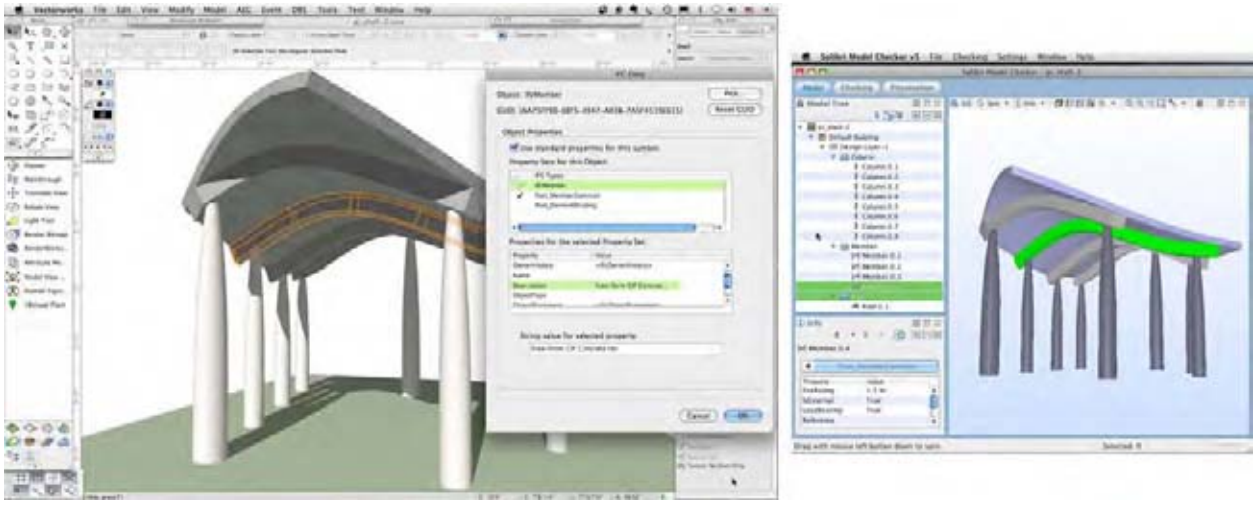


FIGURE 4. Assigning IFC data to a freeform element modeled with Vectorworks' 3D tools. The same model exported in IFC format to Solibri Model Checker is also shown.

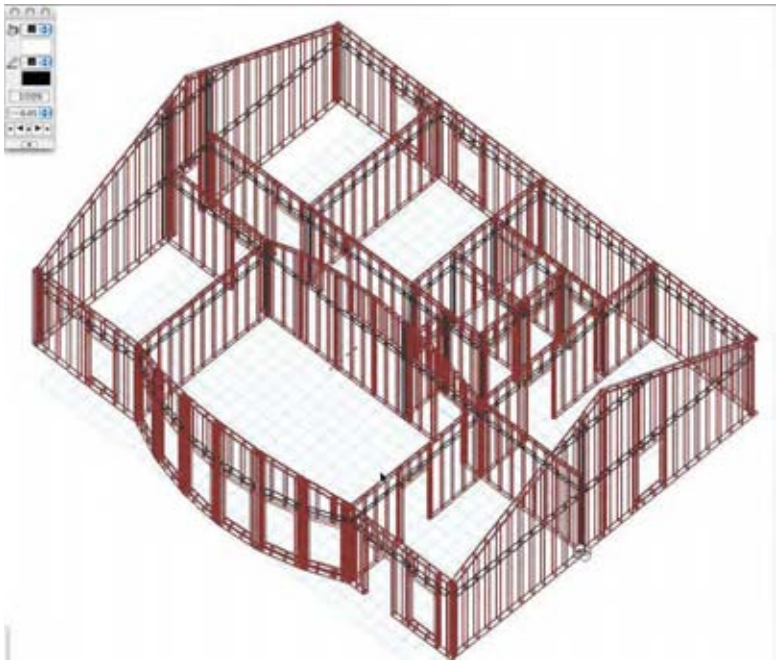


FIGURE 5. Automated wall framing based on rules such as plate material lengths, blocking style, opening framing style, etc.

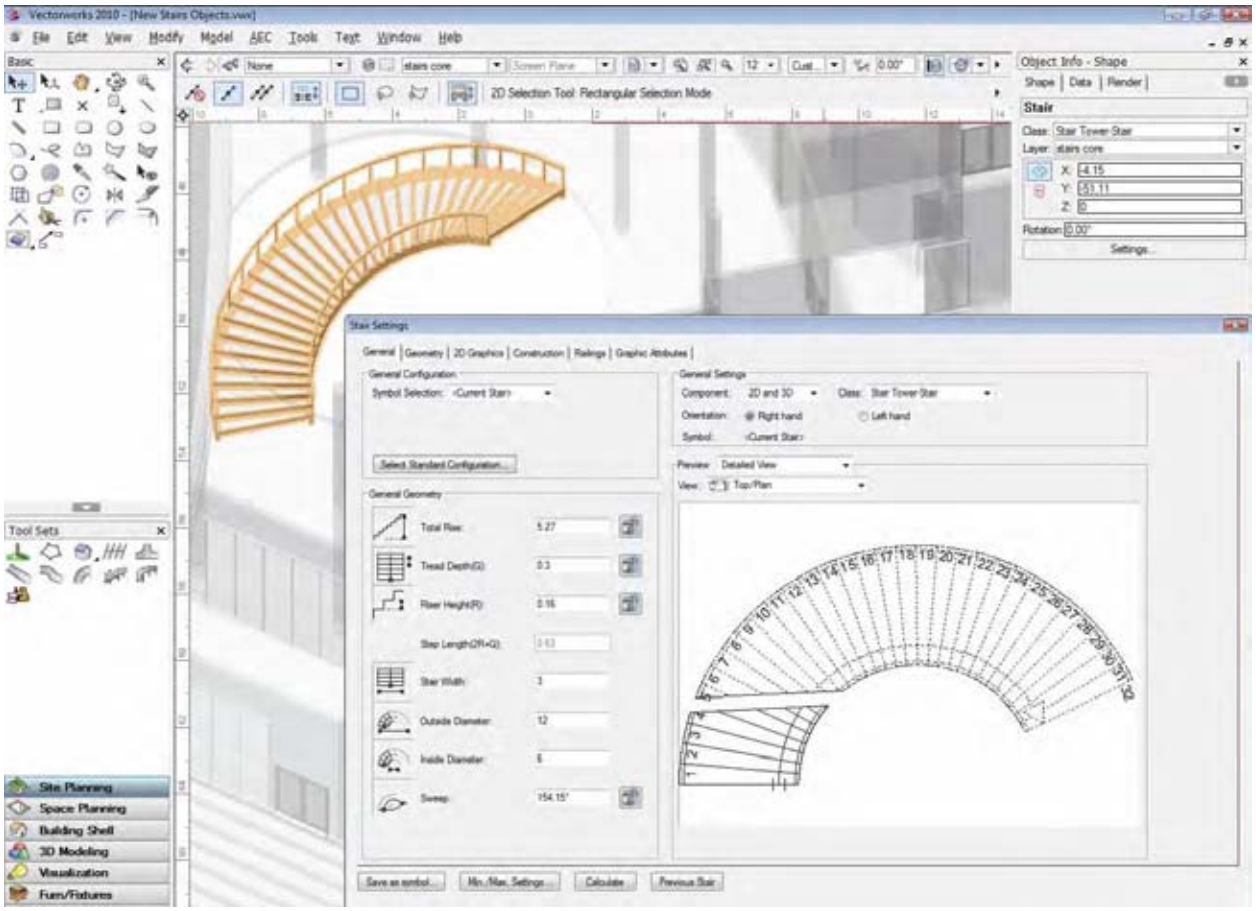


FIGURE 6. Parametric Stair tool in Vectorworks Architect.

DISCUSSION

This section discusses some of the key features of Vectorworks Architect in more detail.

Project Setup

Vectorworks uses a centralized BIM approach similar to Revit and ArchiCAD, where the model and all associated drawings and schedules are contained in one file by default. For a large project with multiple team members, however, the recommended approach is to break up the project into multiple files, to keep the individual files sizes to a manageable level and allow the different team members to work on individual files. There is no ability for more than one user to be working on a file—there is no concept similar to Revit's worksets or element borrowing, or ArchiCAD's Teamwork module. Vectorworks uses standard referencing technology to assemble the multiple files into a single BIM, which can then be used to derive the drawings, schedules, renderings, animations, and other deliverables. Common project resources such as project settings, element styles, materials, symbols, hatches, library elements, and so on can be contained in a shared project template file that is linked to each one of the individual project files using a workgroup referencing link.

Setting up a new project in Vectorworks is accomplished using three main commands: Document Setup, where you specify drawing-related aspects such as units, scale, drawing area, grid, text and dimension styles, sheet border, and title block settings; Model Setup, where you specify the number of levels and the height and elevation of each level of the building model; and Create Standard Viewports, where you specify the different kinds of sheets you will eventually want to print (see Figure 7). The second and third commands automatically create the design layers, sheet layers, classes (different categories of building elements), views, and viewports that will be needed for the project. Elements on different levels are modeled by activating the view for that level; they will automatically have the correct heights and elevations. All of the project settings can be saved as a stationery file for re-use. Firms can create many stationery files for different project types to avoid having to go through the setup process for every new project.

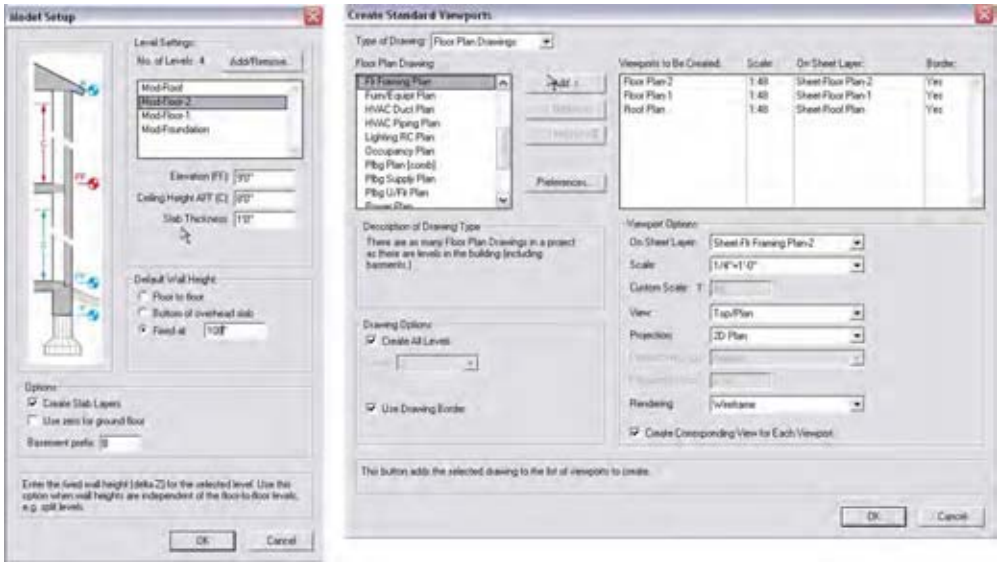


FIGURE 7. The dialogs for Model Setup and Create Standard Viewports for project setup in Vectorworks Architect.

While the project setup in itself is not complicated, the downside is that it relies extensively on dialogs and is not very interactive. For example, you cannot change the height of a level graphically; you have to open up the Model Setup dialog to do this. Also, there are five different types of constructs to work with and navigate—design layers, sheet layers, classes, views, and viewports—which can be somewhat confusing (see Figure 8). An application like Revit does not use layers at all, while the other BIM applications use layers internally but prevent them from being prominent in the interface.

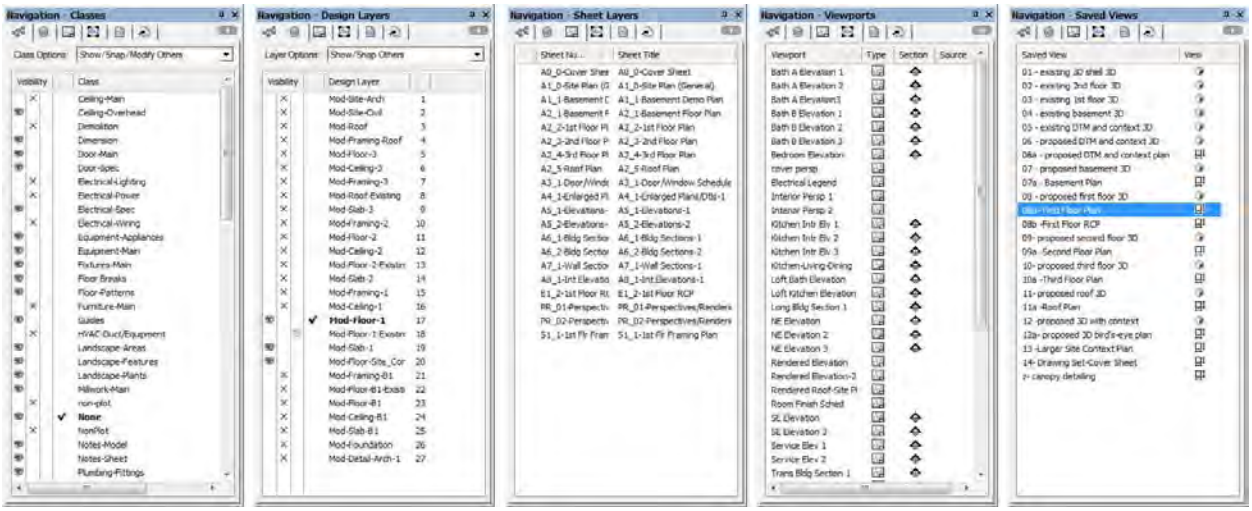


FIGURE 8. The different constructs of a project as seen in the Navigation palette of Vectorworks of an 85MB project file.

Interface

Vectorworks is on par with other BIM applications in allowing precise and accurate modeling. Linear and angular dimensions are displayed as you are modeling (commonly referred to as "heads-up display") and these can be edited to create elements that are sized and oriented exactly as required. When dimensions are added as annotations, these are bi-directionally associated with the model: they update when the model is changed, and changing the dimension value changes the geometry of the associated object. In addition, dimensional and geometric constraints can be applied to 2D objects and some 3D elements such as walls. For example, you can constrain a wall to be horizontal, a hallway to be of a certain width, and so on. These constraints are automatically maintained when changes are made.

Some built-in relationships exist, such as wall to wall connections and space to wall associations, and these are also maintained when modifications are made, making the editing of the model easier. Elements can be readily swapped out for other elements (for example, changing the type of a wall or a door) and any necessary adjustments are made automatically. 3D snapping capabilities are good, and there are visual cues for movement along the X, Y, and Z axes, both of which are particularly helpful when using the 3D modeling tools to create massing or conceptual design models.

Other interface highlights are a hybrid 2D-3D environment that allows the 3D view of a floor plan to be seen "on top" of the 2D construction lines used to develop it (see Figure 9); a "Select Similar" tool that allows similar objects to be quickly selected based on a wide range of criteria such as object class (wall, window, etc.), object type (e.g., interior or exterior wall), element properties (such as material), and so on; easy adjustment of object appearance in 2D as well as planar views; and a Resource Browser that provides easy access to different elements and element types, with parametric objects indicated in red to make them readily distinguishable.

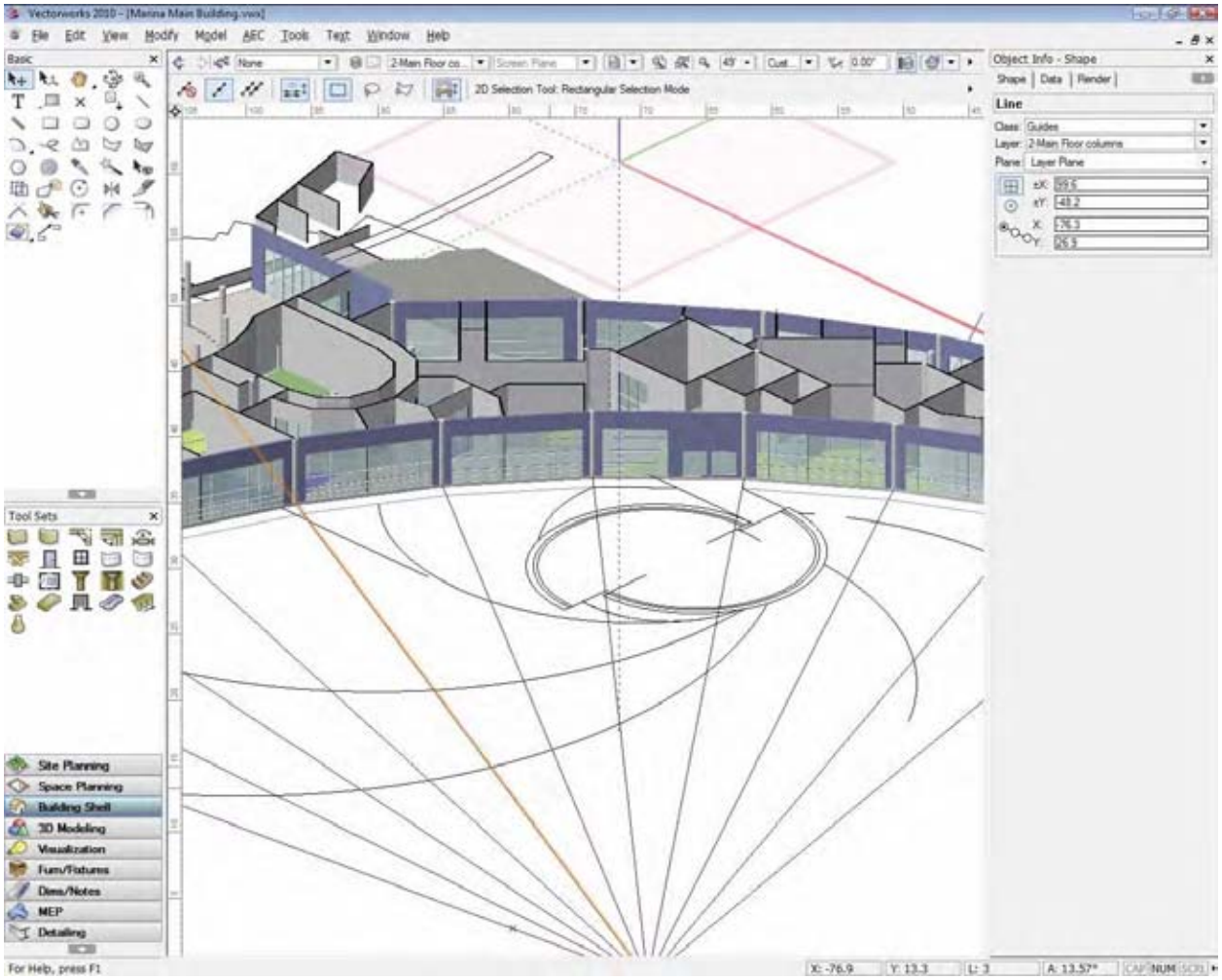


FIGURE 9. Vectorworks' hybrid 2D-3D environment allows a 3D view of a floor plan to be seen along with its 2D reference lines.

At the same time, the interface of Vectorworks Architect is also quite quirky and doesn't seem to have fully caught up with BIM and 3D. There is still the antiquated concept of 2D "screen objects" which are always displayed parallel to the computer screen. By default, 2D elements are created as these screen objects as opposed to planar objects, leading to a strange juxtaposition of 3D objects and 2D screen objects in 3D views as shown in Figure 10, until the user figures out what is going on and changes the 2D setting to create planar objects.

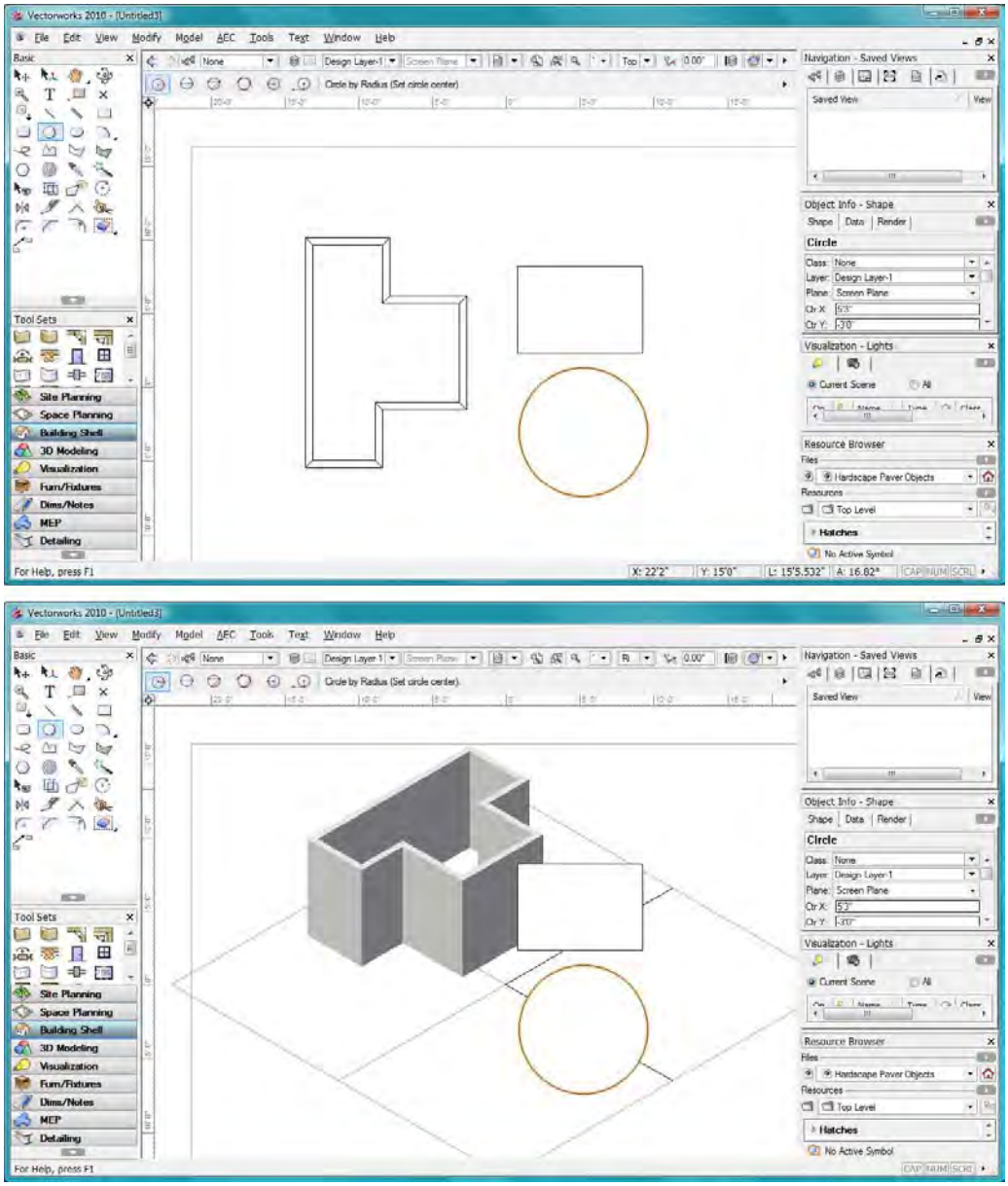


FIGURE 10. The object on the left was created with the Wall tool, while the objects on the right were created with the 2D drawing tools. The 2D elements are created on the screen plane by default and therefore do not appear correctly in 3D.

Similarly, a "Unified View" option needs to be selected if the building model is to be seen correctly with all the different levels at the correct heights. If this option is not checked, the model is not displayed correctly, as shown in Figure 11. Many of the tools are not interactive; for example, the Extrude tool—you cannot specify the object height interactively, only through a dialog. The interface is also a little lacking in consistency. For instance, the Floor tool does not appear in the same toolset as the other building element tools, or in any other toolset. It can only be selected from the main menu bar. Also, you cannot create a floor slab directly—you can only convert a 2D element to a slab, which means that you have to draw the 2D element first or derive it from the wall outline. When changes are made, they are not always updated in the different views automatically; the views have to be refreshed to see the changes.

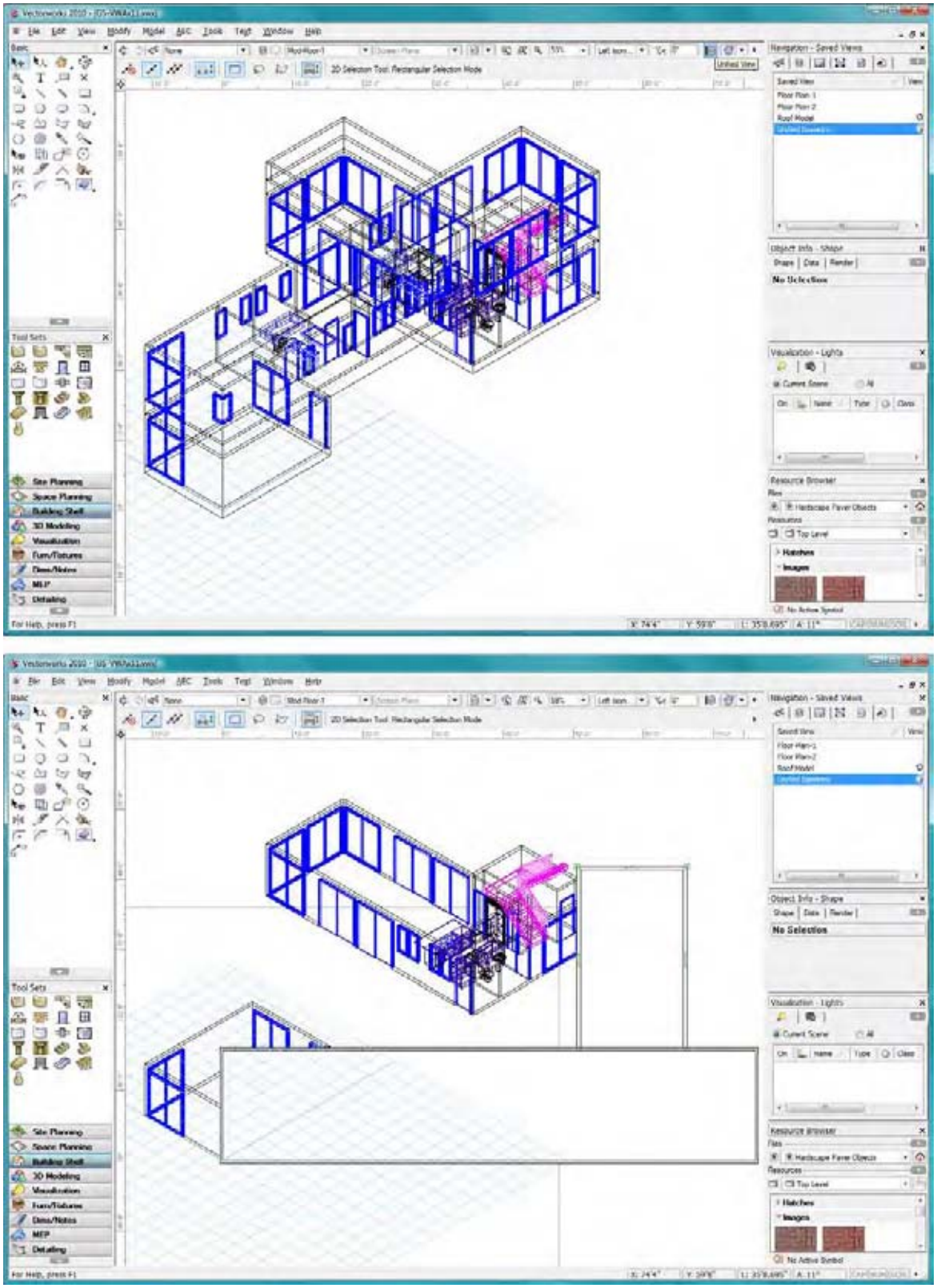


FIGURE 11. Comparing a 3D view of a building model with the "Unified View" option on (top image) and off (lower image). The "Unified View" option shows the model correctly.

Functionality

Starting with version 2009, Vectorworks Architect incorporated the Parasolid modeling engine, a proven technology developed by Siemens that is well established in the manufacturing industry. This has greatly improved the 3D modeling capabilities—both traditional and free-form—of the application. All of Vectorworks' 3D design tools, building elements such as roofs, as well as some 2D tools are powered by the Parasolid modeling library. Parasolid supports multi-threading and has speeded up the modeling operations by 4 to 5 times compared to older versions of Vectorworks.

Some aspects of Vectorworks' building modeling tools are very well developed. For example, for modeling walls, there is an extensive library of different wall styles with properties that can be customized such as the different components making up the wall, 2D display options, texture options for 3D displays, and the ability to add data such as fire rating, thermal resistance, manufacturer, URL, etc. Walls automatically join with other walls as they are being created. Walls can be easily reshaped to have a varying elevation, and you can add points that can be moved to create more complex profiles (as shown in Figure 12). It is also easy to add features such as projections and recesses to walls using 3D solid modeling tools (as shown in Figure 13). The sculpted wall still retains its BIM nature (intelligence and behavior), its properties, the wall projection, and so on. When two such sculpted walls are joined, the wall components match correctly to their counterparts in the connecting wall.

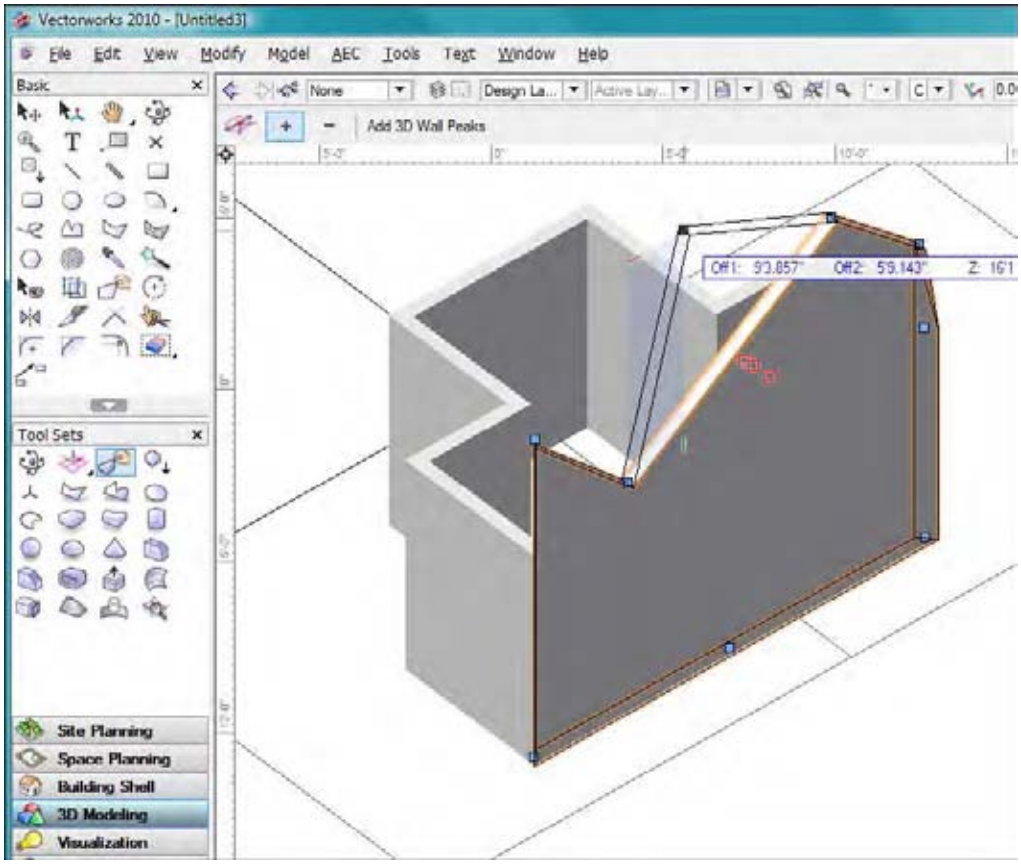


FIGURE 12. Reshaping a flat wall in Vectorworks Architect by adding points and changing their elevations.

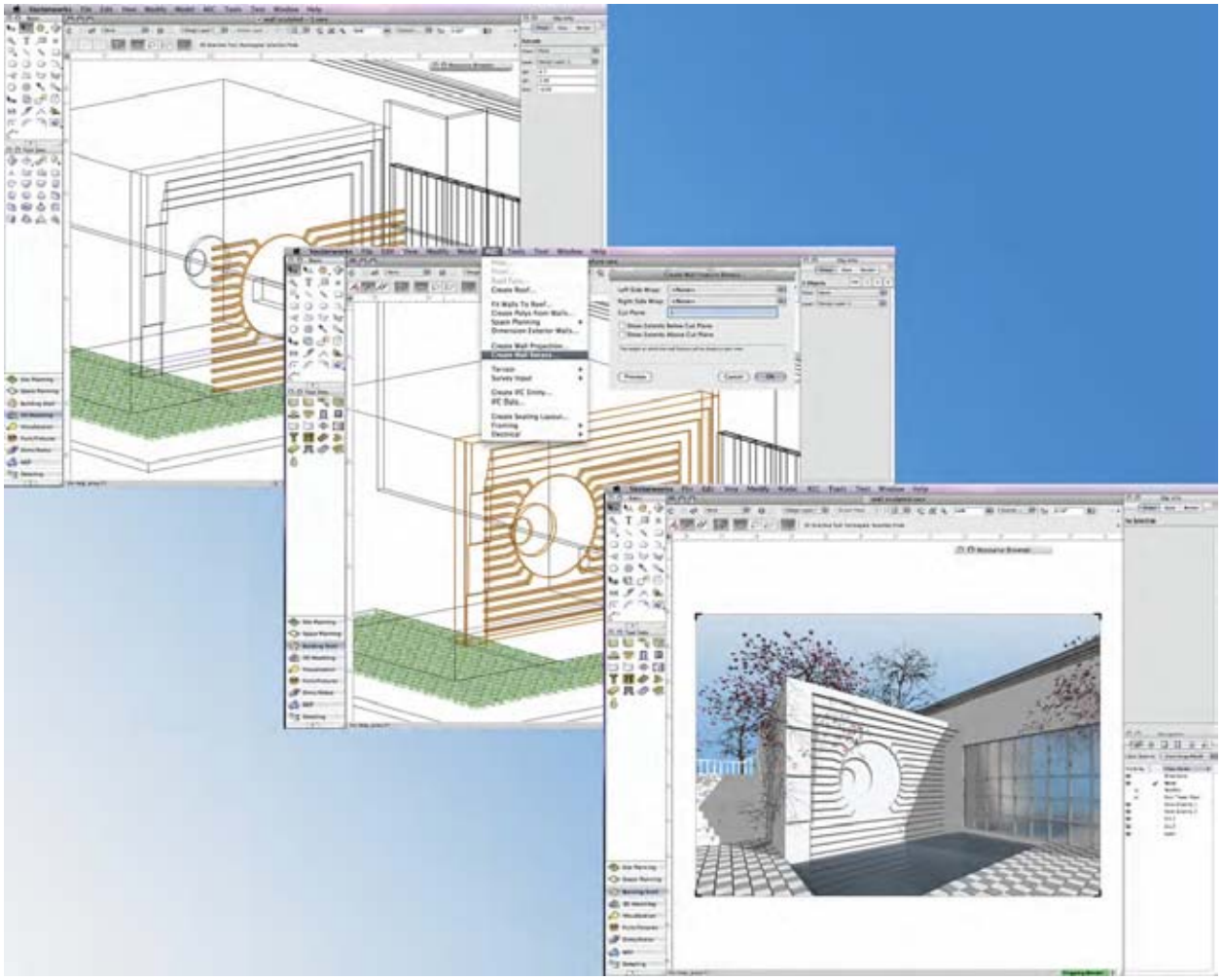


FIGURE 13. Using the Wall Recess tool to add a complex shaped recess to a wall.

Other modeling highlights include the ability to easily place elements such as corner windows; a custom stair object that supports a large number of configurations to create complex staircases; a tool for dynamically reshaping 3D roofs; roof accessories such as attics, soffits, and fascia; a dedicated toolset for modeling MEP objects; and advanced site modeling tools including cut and fill calculations. There are also automatic roof and wall framing tools with the ability to get detailed quantity information of the framing in a schedule for cost estimation and construction, a feature that is especially useful for residential designers. The product's focus on residential design also shows in its content library, which includes lots of content for homes such as skylights, fireplaces, furniture, fountains, audio/video and home electronics library, etc.

Where the modeling repertoire of Vectorworks comes up short is for elements such as curtain walls, floors, and structural components such as beams, for which both the modeling interface and the options are very limited. The problems with modeling floors were described in the previous section. Beams in Vectorworks Architect can only be created as part of the framing of the roof; there is no independent Beam tool. There is a Column tool, but this is for creating decorative architectural columns only. The assumption is that structural elements will be modeled elsewhere, not in the architectural model. While this may be true, all the other BIM applications do include the tools to create basic structural elements in the architectural model, so Vectorworks is a little behind in this regard.

On the rendering front, the Renderworks plugin module, which can be added for only an additional $400, greatly enhances the ability of the application to create advanced photorealistic renderings and animations right within the application. Based on the leading Lightworks rendering engine, Renderworks incorporates ray-tracing as well as radiosity-based illumination and includes features such as multiple decal texturing, blur reflectivity shaders for more realistic reflections, intuitive texture mapping controls, the ability to drag and drop textures on the faces of 3D objects and have different textures on individual faces, 3D entourage such as plants that render quickly and look realistic, and support for HDRI (High Dynamic Range Images), which makes creating realistically-rendered objects and exterior scenes easier. A Camera tool is available to set precise views. Renderworks allows three different types of animations to be created: standard fly-overs about a point in space; walk-throughs with a moving camera; and daylong solar/shadow study for a given location and day of the year. Animations are created in Quicktime MOV format. Renderworks also includes an Artistic mode for creating more artistic and less photorealistic looking images when required.

Similar to other BIM applications, drawings in Vectorworks are simply different views of the model and are created as viewports placed on sheets. Some viewports such as plans and elevations are automatically created during project setup, although for elevations, settings have to be changed to actually set the viewport to the required elevation view, which is counter-intuitive. Viewports with 2D or 3D sections can be generated by drawing section lines where required. Plan and elevation viewports are automatically updated when changes to the model are made; for sections, however, an Update command has to be selected to see the changes. For each viewport, you can specify the layers and classes that should be visible in it, as well as the display style (see Figure 14).

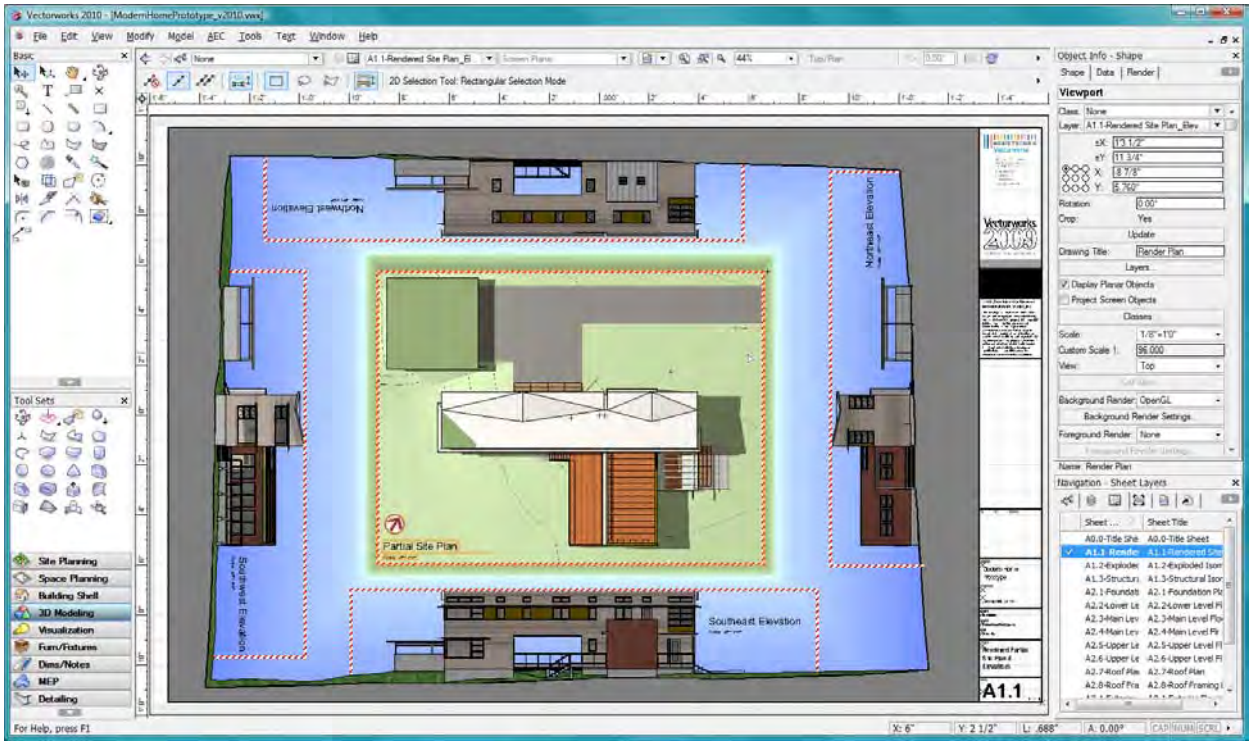


FIGURE 14. A drawing sheet composed of several viewports. Viewport properties can be set in the dialog shown on the right.

Dimensions and annotations can be added directly in the model views or in the viewports. For dimensioning, there is a convenient tool that dimensions all the exterior walls and openings of a floor plan with a single command. Similar to other BIM tools, there is automatic coordination of sheet numbers and drawing numbers among sheet borders, drawing labels, and section markers, eliminating cross-referencing errors. Other key documentation-related capabilities include a Notes Manager for easily managing drawing notation callouts and keynotes, and a set of Redline tools that provide the ability to annotate drawings with redlines and sketches and keep track of redline objects and any changes, corrections, and revisions that occur in a drawing.

CONCLUSION

While there is much to appreciate in Vectorworks Architect—its wide range of capabilities that come at less than half the cost of other BIM applications—it has some crucial limitations that hamper its ability to be adopted as a BIM application on a large scale. Its modeling toolset for BIM cannot be considered complete without better tools for modeling elements such as floors, curtain walls, and structural elements; its interface still carries over a lot of "baggage" from its CAD roots and is not fully updated for BIM; its project setup for BIM is cumbersome and confusing with far too many constructs including classes, design layers, sheet layers, viewports, and views; and it does not provide any specific support for large projects, model collaboration, and distributed workflows.

For those used to the relative power and sophistication of applications such as Revit and ArchiCAD, working with Vectorworks Architect can be extremely frustrating. The application is, at this stage, best suited to users and firms that are just beginning the transition to BIM from 2D CAD applications—it allows them to work in 2D using their existing CAD standards, design in 3D with free-form surface and solids modeling tools, or merge 2D and some BIM modeling in a hybrid design environment. It's relatively low cost compared to the other BIM applications also makes it ideal for this purpose. That said, given the enormous progress the company has made in the last few years on its BIM capabilities, one cannot rule out the possibility of even more rapid progress in overcoming the limitations described here and becoming a serious BIM contender in the future.

Digital Project

Digital Project is a CATIA-based BIM application developed by Gehry Technologies (GT), a spin-off company from Frank Gehry's architecture firm that was established in 2002 to disseminate his CATIA-enabled design and construction methodologies (described in the AECbytes article, "Technology at Work at Gehry Partners: A Case Study") to other design firms. CATIA is developed by Dassault Systèmes and is the leading design software utilized in the aerospace and automotive industries. Being built on top of CATIA makes Digital Project very powerful and sophisticated but also very complex and expensive, compared to other BIM applications.

Digital Project uses a granular file-based structure for its models which comes straight from its mechanical CAD roots, where a model is hierarchically composed of "parts" that come together to form higher-level assemblies called "products." A building model can be composed of hundreds or even thousands of files, depending upon the level of granularity required. This federated approach to modeling, along with a special visualization technology that loads geometry only on demand, allows Digital Project to handle projects of any complexity. Also, its CATIA-based engine provides it with the ability to precisely model any kind of form as well as derive the necessary fabrication information from it. Thus, while Digital Project is not widely used in design firms because of its cost and complexity, its ability to handle large projects with challenging geometry—unmatched by any of the other BIM applications—has attracted a select group of users and allowed it to establish a niche for itself within the industry.

Apart from its parent company, Gehry Partners, one of the few architectural firms that is known for its implementation of Digital Project is Skidmore, Owings & Merrill LLP (SOM). However, SOM does not implement Digital Project as its main BIM application but only uses it selectively for parts of projects that require its sophisticated freeform modeling capability. This is why SOM's work with Digital Project is not featured among the ten projects that are showcased in Digital Project's portfolio on its website. Three of these are by Gehry Partners, indicating that it is still the main client of the software. Another key client whose projects are featured in the software's portfolio is Swire Properties, a large owner/developer based in Hong Kong. Swire has been using Digital Project, along with Gehry Technologies' related consulting services, for design coordination and clash detection on many of its high-rise projects such as One Island East, a 70 story office building (see Figure 1). Gehry Technologies has, in fact, disclosed that it generates most of its revenue by providing consulting services related to the implementation of Digital Project, often on behalf of the owner and typically for large and complex projects, rather than by outright sales of the software. Another recent project where Gehry Technologies has been working as a consultant is the Lincoln Center Alice Tully Hall in New York, designed by Diller Scofidio + Renfro (see Figure 2). It is using Digital Project to model the different systems and components making up the complex design interior and developing the surface models for the wooden panels to send directly to fabrication, ensuring a precise fit.

Given the complexity of the application, it seems unlikely that Digital Project can be deployed without the consulting services of Gehry Technologies, and this does restrict how many projects it can take on and the number of users it can support. This is probably the reason why Gehry Technologies seems content to remain a niche player in the BIM technology industry for now, and has not been very aggressive in pushing the use of its software to the mainstream architectural community. Unlike the other BIM vendors, Gehry Technologies does not exhibit at trade shows such as the AIA or make its presence felt in technology-oriented conferences such as the AIA TAP (Technology in Architectural Practice). Thus, it is largely unknown in the AEC industry, except as being the tool that is used by Frank Gehry's firm.

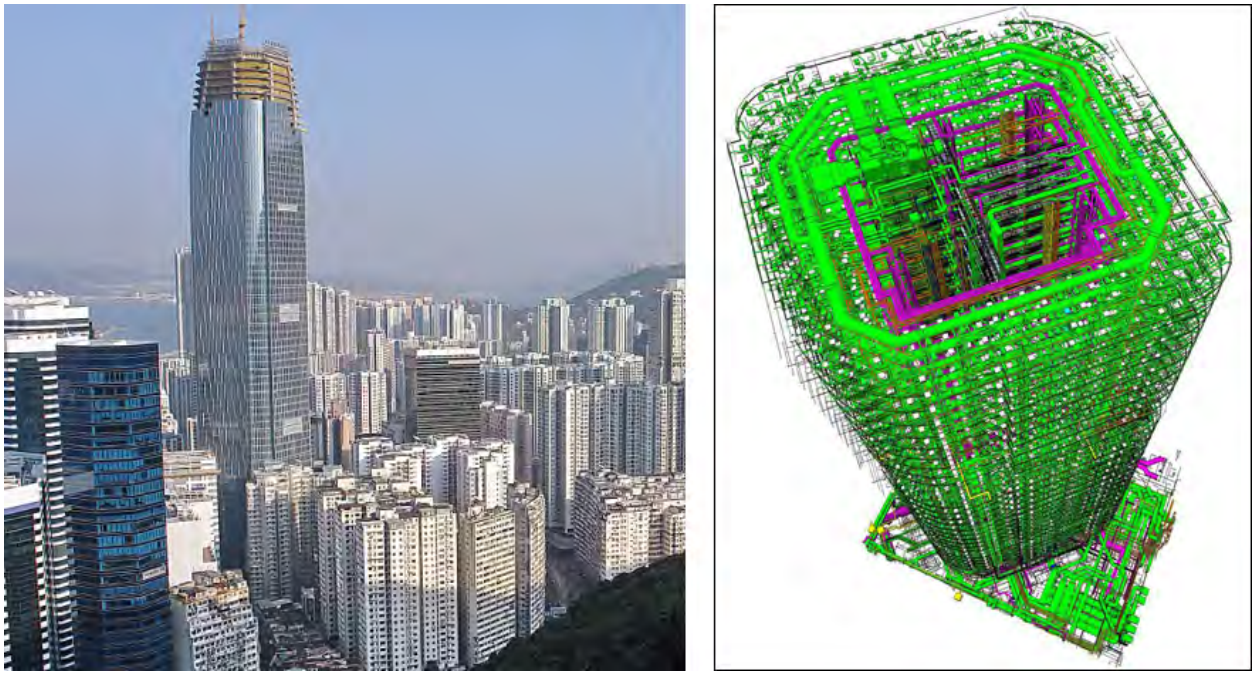


FIGURE 1. The One Island East project in Hong Kong by Swire Properties, on which Gehry Technologies was hired as the BIM Consultant for the use of Digital Project.

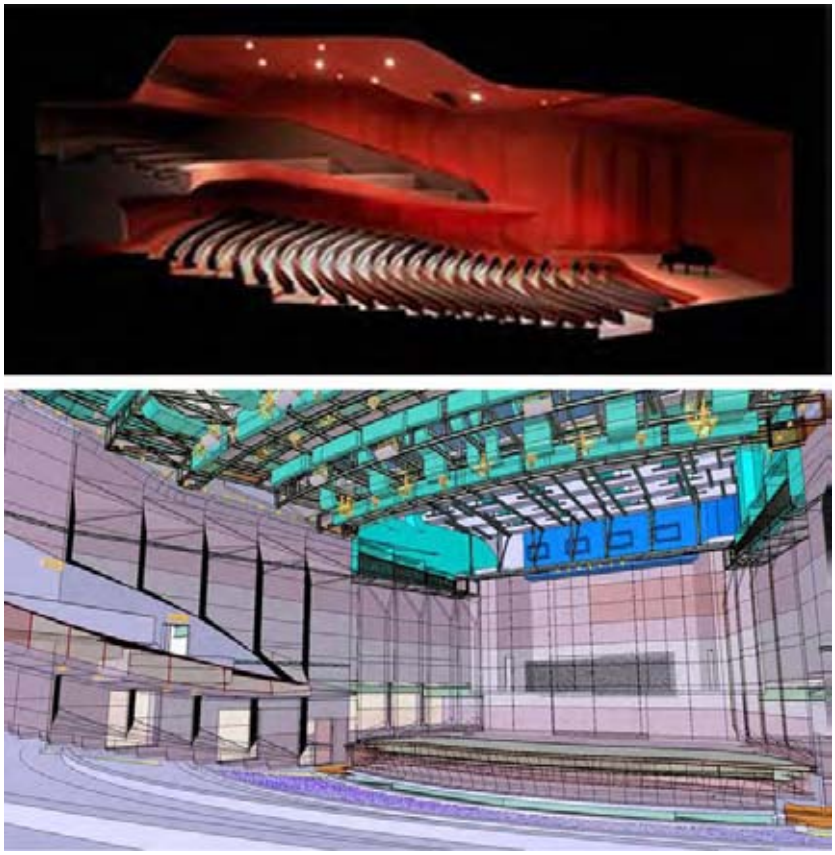


FIGURE 2. The Lincoln Center Alice Tully Hall in New York, one of the other major projects on which Digital Project is being used.

EVALUATION SUMMARY

Key Strengths

- Allows highly complex freeform geometry to be modeled to which building attributes can be added to create a BIM model and from which accurate fabrication information can be derived
- Federated file-based approach allows for the modeling of very large projects to a high level of detail
- Uses a special representation technology that allows even very large projects to be easily opened on a low-end computer
- Model is full parametric, and any change is automatically and intelligently propagated to all associated elements, even if they are in different files
- Powerful Search tool that can be used to find elements with desired attributes and save them in selection sets for future re-use
- Supports a multi-disciplinary workflow, with built-in tools to model architectural as well as structural elements and an add-on for MEP modeling
- Several additional add-on products are available for advanced rendering, Primavera integration, surface modeling, and knowledge capture and re-use
- Supports the IFC file format for interoperability with other BIM applications
- A separate Viewer application is available for the use of consultants, clients, contractors, and others for 3D model navigation, measurement, coordination, and review

Main Limitations

- More expensive compared to other BIM applications
- Extremely complex application that is conceptually very different from any other building design or CAD tool, and therefore usually requires consulting services from the vendor to go with it
- Vast toolset that can be mastered only by highly technology-savvy individuals
- Building modeling interface lacks fluidity and interactivity, making it difficult to use as a design tool
- Overall interface is more functional than user-friendly and lacks any kind of "wow" factor
- Limited amount of built-in catalogs with BIM content available to users
- No real-time model collaboration capability; files have to be updated to see the changes made by other team members
- Takes a long time to open up—close to 5 minutes on a brand new computer (Intel Quad Core, 2.33 GHz, 8 GB RAM)
- Company not very open or responsive to requests for information
- Relatively unknown compared to the other BIM applications, with limited usage and little published information available online

Price

- Exact pricing varies upon the package selected and was not disclosed, but is about twice the price of other applications.

DETAILED EVALUATION

Application Repertoire

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Space Planning/ Programming			✓	Does not include any space planning or programming tools.
Conceptual Design/ Mass Modeling		✓		Includes tools for advanced parametric 3D surface and solids modeling and free-style surface modeling (NURBS), but these are very complex and not suited to preliminary design conceptualization. A separate "Imagine and Shape" add-on is available for more quick and intuitive freeform modeling, and while this is very powerful, it lacks the fluidity, interactivity, and ease of use of a tool like SketchUp.
Detailed Modeling	✓			Allows detailed and precise modeling of all architectural and structural building elements including walls, doors, windows, rooms, slabs, beams, columns, stairs, and curtain walls.
Schedules and Reporting	✓			Uses Microsoft Excel (required to be installed) to generate various kinds of data reports from the model, including schedules. There are also dedicated tools for generating door and window schedules. There is bi-directional integration between the Excel data sheets and the model; any change made in one can be updated in the other. (*See Figure 3*)
Quantity Take-off	✓			There are many advanced measurement tools to get information from the model, including a specific tool to calculate quantity information. These are displayed along with the model and can also be captured in Excel data sheets.
Photorealistic Renderings	✓			Two advanced rendering add-on products are available: Photo Studio, which generates high-quality, photo-realistic renderings and animations; and Photo Studio Optimizer, which uses advanced rendering technologies such as global illumination and caustics (more accurate reflections and refractions) to produce even more realistic renderings and animations. (*See Figure 4*)
Animations	✓			Realistic animations can be created using either the Photo Studio or Photo Studio Optimizer add-ons. Digital Project also includes distributed rendering capability that enables up to 24 CPUs to be used simultaneously for rendering, allowing animations to be created in a reasonable time frame.
Real-time Model Exploration		✓		Includes several model navigation tools and mouse-shortcuts for exploring the model within the modeling environment. But there is no dedicated mode or environment that allows easy game-like navigation and exploration of the model, similar to what ArchiCAD has.

Construction Documents		✓		Includes tools to create drawing sheets with plans, sections, elevations, and other views generated from the model, and apply dimensions, annotations and dress-up elements to these drawings. However, the 2D functionality is not as well developed as that of AutoCAD or even the other BIM applications. The drawings are created in a separate file, and are not automatically updated when the model changes. An Update command has to be run for each individual sheet to update it.
Coordination/ Clash detection	✓			Includes powerful interference checking and analysis capabilities, ranging from a simple detection of interferences between parts (different components of the model contained in separate files) to a detailed clash, contact and clearance analysis of models and/or elements within a model.
Fabrication	✓			Exports to STL format for rapid prototyping and computer-aided manufacturing; also supports the STEP format for detailing and fabrication.

Intrinsic Nature and Capabilities

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Intuitiveness and Ease of Use			✓	Extremely complex interface that would take even a highly tech-savvy user a steep learning curve to master. Since the application is built on top of a high-end mechanical CAD application used in the aerospace industry, it is unlike most CAD and BIM applications commonly used in the AEC industry.
Ease of Project Setup			✓	Project setup is based on the MCAD concept of products and parts, which is unfamiliar to AEC professionals and is therefore not easy to work with. Individual components of the model are created in "part" files that are assembled together into "product" files. A building model may be comprised of several product and part files.
Information Re-Use		✓		Most of the building elements are modeled from or created in reference to existing elements such as grids, planes, lines, points, surfaces, and so on. However, there is no tool to quickly create a building model from a massing model of the kind that Revit has.
Modeling of Organic Building Forms	✓			This is one of the core strengths of the application. It includes a vast array of 3D solid, surface, and freeform modeling tools, which can be used to create highly accurate 3D geometry that in turn can be used to define building elements to which additional construction-related attributes can be added. Both the Uniformat and CSI attribute schema are supported.

Automation of Tasks		✓		While Digital Project allows programming and scripting languages such as Visual Basic, VBScript, and Jscript to be used to write sophisticated applications to automate modeling and other tasks, it does not have any built-in automated tasks such as creation of beam arrays, roof and wall framing, and so on.
Creation of Parametric Forms	✓			This aspect is where Digital Project really shines. It enables the creation of a fully parametric building model where all the elements are connected to each other and the configuration is driven by some key parameters. Any change to the value of a driver, or any change to any element of the model, is intelligently propagated throughout the entire model, maintaining its integrity.
Associative Behavior of Building Elements	✓			Since all the building elements are modeled from or created in reference to existing elements, any change that is made is automatically propagated to all associated elements.
Guarantee of Model Integrity			✓	There is no semantic knowledge of buildings that would automatically dis-allow physically impossible situations such as overlapping doors. Such conflicts can only be detected and fixed by clash detection tools.
Availability of BIM Content			✓	Comes with basic catalogs for doors, windows, wall types, steel sections for columns and beams, stairs, railings, ramps, and MEP objects, all of which are IFC compatible (*see Figure 5*). Custom content can be created and added to the catalogs. There is no third-party content development.
Customization Capability	✓			Includes a large number of customization options to control different aspects of its interface and functionality.
Support for 3D Printing	✓			Come with an STL Translator add-on that provides both STL import and export capabilities. It enables accurate tessellation of CAD data, along with tools for improving mesh quality by removing and reorganizing triangles. The repaired meshes can be exported as standard binary STL files to create machinable mock-ups in 3D printers.
Multi-Processing Support			✓	Digital Project does not support multi-processing.
64-bit OS Support	✓			Digital Project comes in both 32-bit and 64-bit versions.
Cross-Platform (Windows, Mac)			✓	Digital Project is a Windows-only application.

Issues Specific to Large Firms

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Model Performance	✓			The model is opened in a special visualization mode that does not load the complete geometrical and attribute data for all the individual building components. The enables even a low-end computer to be used to view large models. Only when the user selects an element to be edited, the "part" file containing that element is fully loaded.
Model Sharing Technology			✓	There is no special model-sharing technology apart from the ability to assemble different components of the building modeled in different part files into a project file. Collaboration requires communicating by voice or email as the model alone cannot be used for collaboration.
Support for Distributed Workflow		✓		The project is broken up into multiple files, and one user can work on one file at a time. Changes to other files cannot be seen in real time; files have to be updated to see the changes. A dedicated Project Standards application is available for multiple-user environments, which allows the 3D Coordinator/Project Manager to control and maintain the same set of standards throughout the project from one centralized location.
Security and Access Controls		✓		These do not come built into the application but can be set up by Gehry Technologies as part of its consulting services.
Performance Across WAN		✓		Since the model-sharing is not real-time but is updated on command, and the model is broken into files, a high bandwidth WAN provides adequate support for the exchange of model information.
Ability to Handle Large Projects	✓			Since the building model would typically be broken down into a large number of files, it allows for very large projects to be modeled and to a high level of detail.

Interoperability

CRITERIA	RATING			COMMENTS
	Good	Fair	Poor	
Integration with Structural BIM Applications		✓		No direct integration with established structural BIM applications. However, it does include some tools for modeling structural elements, the ability to create finite element models (FEM) and export them to IFC structural analysis models, and support for leading structural file formats such as SDNF and CIS/2.
Integration with MEP BIM Applications		✓		No direct integration with established MEP BIM applications. However, it includes an MEP Systems Routing add-on, a conceptual design application that enables MEP planners to reserve the space needed for functional and detail layouts of HVAC, raceways, and plumbing. It includes clash detection capabilities, allowing conflicts between systems, layout, and structures to be detected and eliminated.

Integration with Sustainable Design Tools			✓	No direct integration with any third-party energy analysis tools; Excel data sheet capability can be used to derive data for energy analysis. However, the parametric capabilities can be used to drive the generation of optimal forms for specific energy requirements, but this would require advanced programming and mathematical knowledge.
Integration with Estimating Applications		✓		No direct integration with established cost estimating applications. However, it includes built-in cost estimation capability based on the Uniformat standard. The cost estimation template can be modified according to any other estimating standard.
Integration with Constructability Tools	✓			Supports the STEP format for exporting the model to detailing and fabrication applications. Includes a Primavera Integration add-on that provides 4D construction simulation by linking construction scheduling information contained in Primavera with a project's 3D geometry from Digital Project.
Electronic Publishing and Review		✓		Includes a separate Viewer application, which is a light-weight and easier to use visualization tool for 3D model navigation and review with capabilities such as 2D and 3D annotations, hyperlinks and animation, and publishing to HTML. It also supports 3D XML for sharing 3D data without the use of the Viewer application, but not 3D PDF or DWF, which are more common for model sharing and review in the AEC industry.
Range and Quality of Third-Party Tools			✓	All add-ons are developed in-house; there are currently no third-party vendors developing add-on tools for Digital Project.
Number of 3D File Formats Natively Supported	✓			Imports and exports a wide range of 3D file formats including DWG/DXF, IFC, 3D XML, STL, STEP, IGES, point cloud data, SDNF, and CIS/2.
Quality of API		✓		Does not include a full-fledged, open API (Application Programming Interface). However, it supports scripting through applications such as Visual Basic, VBScript, and JScript.
IFC Support	✓			Supports both import and export of IFC files. All objects created with the architectural and structural tools are exportable to their corresponding IFC objects. Any general geometry model can also be exported to IFC by attaching the appropriate building element attributes to it.

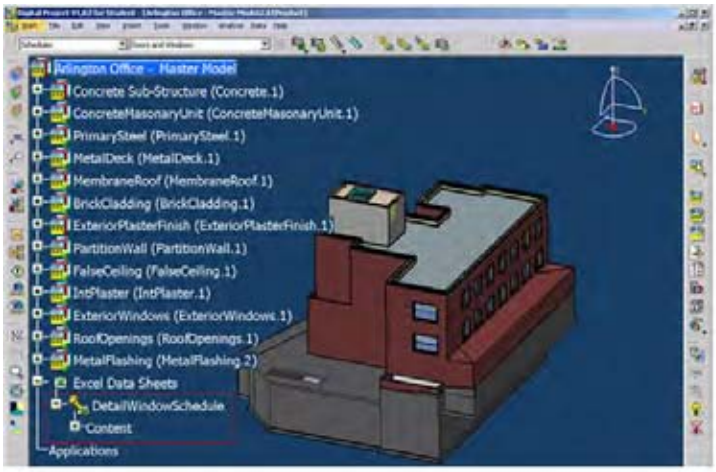
Implementation

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Initial and Ongoing Pricing/Licensing			✓	Extremely expensive compared to other BIM applications.
Initial and Ongoing Training		✓		Except for an introductory online webinar series (that lacks professional quality production), there is no free training. Users can register for paid training events or sign up for customized training at their own location provided by Gehry Technologies for a fee.

Quality of Technical Support	✓			The price of the software includes free support available over the phone or by email.
Quality of Included Documentation		✓		While the Help documentation is very detailed and also includes sample files to make it easier to learn the application, it is only available online, which means it cannot be accessed when the computer is not connected to the Internet.
Free Online Learning Resources		✓		An introductory webinar series comprising eight one-hour sessions is available online, providing a brief overview of the application. The sample project files used in the webinar can be downloaded to work with. In addition, a Digital Project wiki includes additional articles, white papers, tutorials, and sample files. However, this is far from sufficient to learn the application.
Support Channel (Resellers and Consultants)			✓	Gehry Technologies has offices in Los Angeles, New York, Hong Kong, Paris, Abu Dhabi, and Seoul. It currently has no additional resellers or distributors. It provides its own consulting services and has no independent consultants that specialize in Digital Project.
Availability of Trained Staff			✓	The use of the application is so limited and the application is so complex that there are relatively few expert users available. While the software is available to academic institutions (students and faculty) at a steeply discounted rate, the steep learning curve makes it impractical for schools to adopt, except for some very specialized courses or research projects.

Vendor

CRITERIA	RATING			COMMENTS
	Good	**Fair**	**Poor**	
Current Market Position			✓	Relatively limited use in architectural firms compared to other BIM applications.
Long-term Viability	✓			Digital Project is so specialized and sophisticated compared to the other BIM applications that it is likely to continue being implemented for special projects that the other BIM applications cannot handle very well.
Investment in R&D		✓		Since the application is built on top of CATIA, it benefits from all of the R&D invested into CATIA by its developer, Dassault Systèmes, a leading vendor in the aerospace and automotive industries.
Responsiveness to Feedback and Requests		✓		Support requests can be filed online. The Digital Project wiki, in addition to being a learning resource, is also intended for users to learn from and share their knowledge with other users, but I did not find many users actively using it to discuss features and support issues. While my license renewal requests were promptly handled, the company was not very responsive to my questions or requests for information.



			Window				Frame		Details						
	OPENING #	Type	Size Width	Height	Label	Profile	Type	Finish	Head	Jamb	Sill	Bulkhead	Shade	Blinds	Digital Project Object Name
			m	m											
1	W401	<Unset>	2.946	2.134	--	<Unset>	WD	SE	3/6413	<Unset>	4/6481	YES	NO	NO	FixedWindow.1
2	W402	<Unset>	1.727	2.134	--	<Unset>	WD	SE	<Unset>	<Unset>	4/6481	YES	NO	NO	FixedWindow.2
3	W403	<Unset>	1.727	2.134	--	<Unset>	WD	SE	<Unset>	<Unset>	4/6481	YES	NO	NO	FixedWindow.3
4	W404	A	1.727	2.134	--	4/6481	WD	SE	4/6401	4/6401	4/6401	YES	NO	NO	FixedWindow.4
5	W405	B	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.5
6	W406	A	1.727	2.134	--	4/6481	WD	SE	4/6401	4/6401	4/6401	YES	NO	NO	FixedWindow.6
7	W407	A	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.7
8	W408	A	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.8
9	W409	A	2.946	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.9
10	W410	A	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.10
11	W411	A	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.11
12	W412	A	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.12
13	W413	A	1.727	2.134	--	4/6481	ALUM	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.13
14	W414	A	1.727	2.134	--	4/6481	WD	SE	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.14
15	W415	A	1.727	2.134	--	4/6481	ALUM	BR	4/6481	4/6481	4/6481	YES	NO	NO	FixedWindow.15
16	W416	A	1.727	2.134	CC	4/6481	ALUM	SE	4/6481	4/6481	4/6481	YES	YES	YES	FixedWindow.16

FIGURE 3. Example of a window schedule generated from a building model in Digital Project.

FIGURE 4. Examples of renderings created with the Photo Studio and Photo Studio Optimizer add-ons to Digital Project (left and right images respectively).

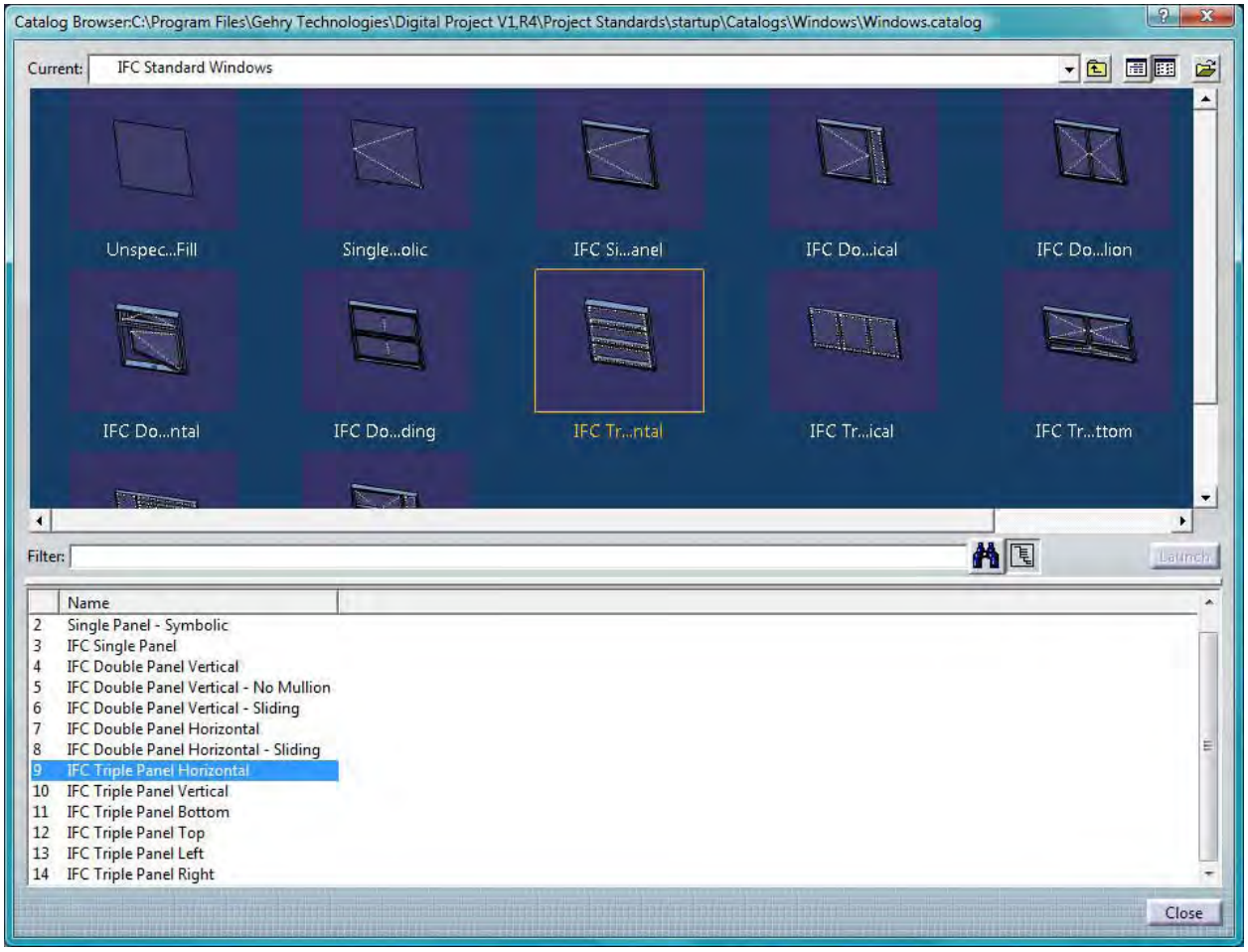


FIGURE 5. The default catalog for window that is available in Digital Project.

DISCUSSION

This section discusses some of the key features of Digital Project in more detail.

Project Setup

As mentioned earlier, Digital Project uses the CATIA approach to modeling, where a model is composed of products and parts. Products are like folders and parts are like the files contained in the folders. Part files contain the actual model geometry. Product files have the .CATProduct file extension and part files have the .CATPart file extension. Products are essentially higher-level organizations of part files. While it is possible to model a small project completely in a single part file—for example, the model shown in Figure 6 is created as a single part file whose size is about 10 MB—this is not the recommended workflow for creating building models in Digital Project.

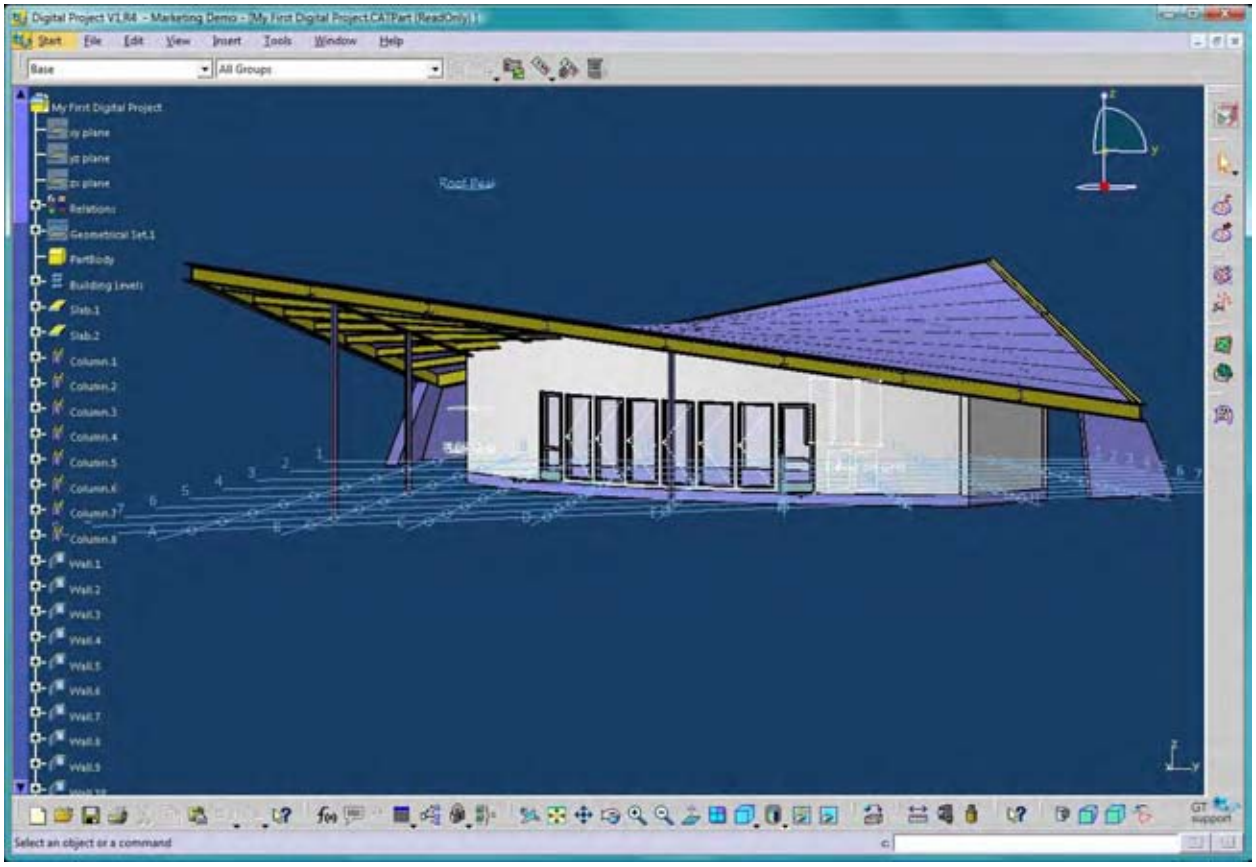


FIGURE 6. A sample Digital Project file where the complete model of a small structure was created as a single part file. Note the .CATPart extension of the file name.

Contrast this with the large building model shown in Figure 7, which comprises 175 files organized in 25 folders and sub-folders, with a total project size of 267 MB. The hierarchical organization of the files can be seen in the "model tree" displayed on the left, where the higher level nodes indicate the product files while the lower level nodes indicate the part files. Two of the lower level nodes have been selected in the model tree, and the corresponding geometry in the model is highlighted in yellow in the graphics window. From the selection, it can be seen that these are portions of the envelope of the building.

All together, seven of these part files containing different portions of the envelope come together to form a higher-level envelope product file. A naming convention for the product and part files reflecting their hierarchy is recommended. So, in this case, the envelope product file is named MAR_B01_ENV, where MAR is the abbreviation of the project name, B01 refers to the building number, and ENV refers to the envelope. This particular project comprises of only one building.

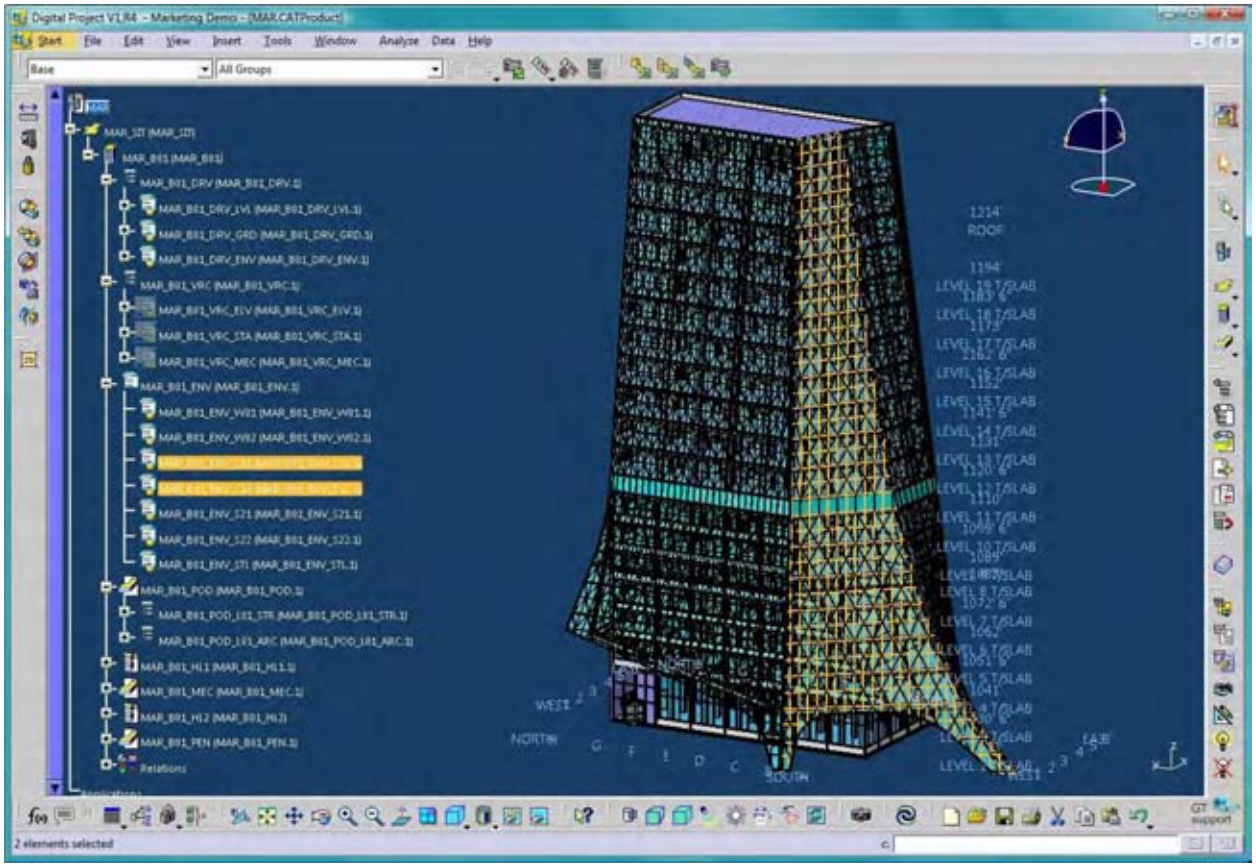


FIGURE 7. A sample Digital Project file showing the model organization of a large building project. Two of the individual part files have been selected with the corresponding objects highlighted in yellow in the model.

While a building model can be organized in different ways as desired by a user or a project team, Digital Project also provides a set of tools for creating a "project structure" based on the IFC standard. This is important if the building model will be used to interoperate with other applications downstream using the IFC format. The Project Structure diagram is shown in Figure 8, along with its implementation in a project as reflected in the model tree. Three categories of the project structure are mandatory: Project, Building, and Building Storey. All the rest are optional, including the site. While there are no site modeling tools as such, you could model any surface using the powerful 3D toolset and designate that component as a site or site section, with attributes that are compatible with the IFC standard.

The Building Storey is typically broken down into the Architectural and Structural components, as shown. Components that relate to the entire building are categorized directly under the Building level. This includes elements such as elevators, stairs, mechanical systems, and so on, grouped under a "Vertical Space Reservations" category, as well as the model drivers including levels, grid, envelope boundary, and any additional parameters that are driving the geometry of the model. Changing the drivers automatically changes the model as it is fully parametric.

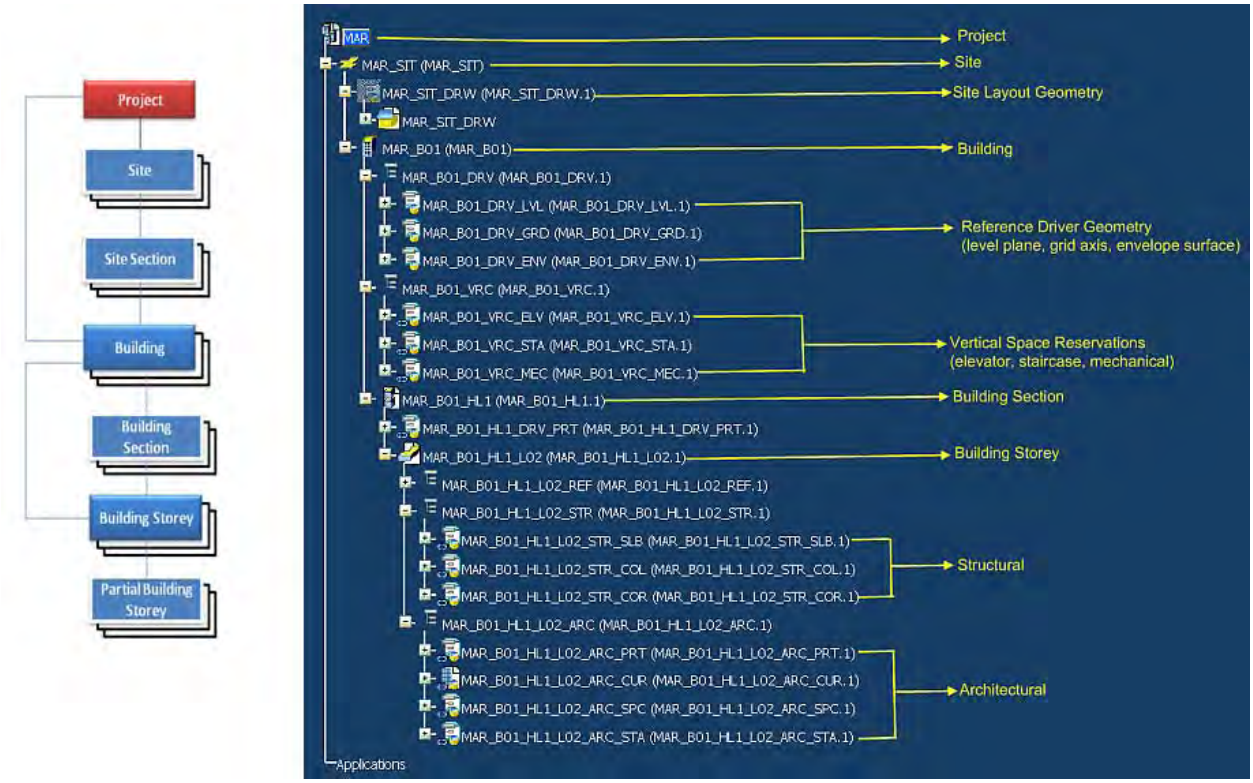


FIGURE 8. The Project Structure option that organizes a building model for compatibility with the IFC format. The conceptual diagram is shown on the left, while its implementation on a project is shown in its model tree on the right.

The multiple-file based approach of Digital Project is what allows it to deal with large projects and model them to a high level of detail. This is also its approach to collaboration and large distributed workflows, as individual members of the team could simply work on different files from any part of the world. A team member can check out a file from the central system to work on; other team members can still see this file, but they will not be able to over-write it. After a file has been worked on, it can be checked back into the system. The changes to that file, as well as any resultant changes to other elements, are updated in the central system. It is a simple approach to collaboration, similar to that of other multiple-file based BIM applications like Bentley Architecture and Nemetschek Allplan. The difference, however, is that the project does behave as one integrated model even though it is distributed across multiple files—any kind of parametric change ripples through all the affected files. Apart from following the basic project structure shown in Figure 8, the project team can decide the level of granularity of the project based on the desired file size for easy check-in and check-out, and on how the modeling work is going to be divided up between different team members.

Interface

The interface of Digital Project is quite different from that of other BIM or CAD applications and takes a while getting used to. The most unique aspect of the interface is the model tree displayed to the left of the model, as shown earlier in both Figures 6 and 7. Also known as the "data view," the model tree displays the complete hierarchical organization of the model right down to the level of each individual element and its attributes, including type, material, and geometry, as shown in Figure 9. Selections can be made in either the model tree or in

the graphical view of the model displayed in the window; in both cases, options are available to zoom into the corresponding elements in the model or model tree respectively. So, for instance, in Figure 9, the column was selected and the option "Center Graph" (available by right-clicking on it) was used to expand the model tree to show information about the selected column. The "Reframe On" option would do the same if a selection was made in the model tree—it would zoom into that element in the model view.

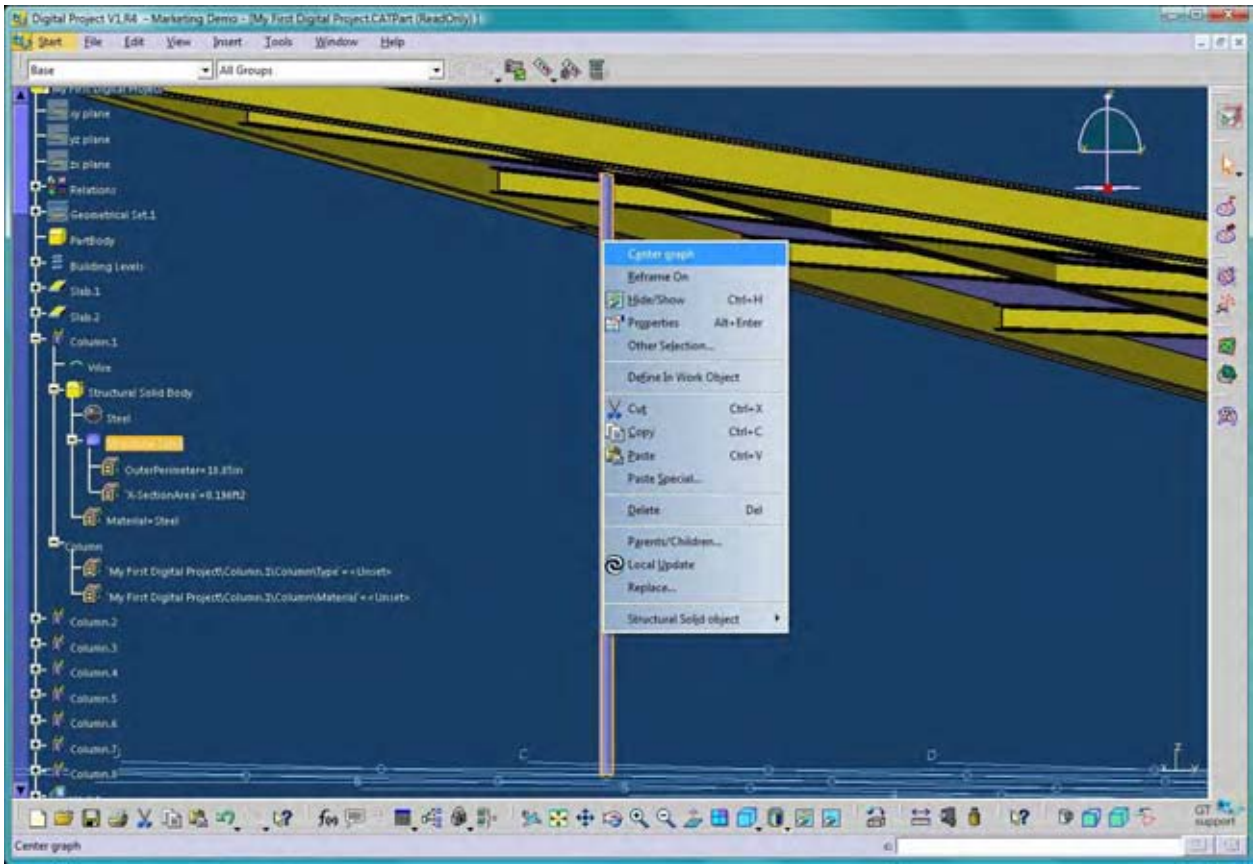


FIGURE 9. Selecting a column in the model and selecting the "Center Graph" option to open up the model tree to show all the details about it.

The example shown above was that of a part file. In the case of a product file composed of many product and part files, such as the large building project shown in Figure 7, the entire model is not loaded when the main project file is opened. Instead, the model is opened in a special mode called CGR (computer graphic representation), which is a low-level display mode indicated by tessellation, as shown in the top image of Figure 10. Selecting the "Center Graph" option after selecting this object only displays the part file to which it belongs in the model tree. To access the individual components of this part file, you have to double-click on it. This changes it from a CGR mode to an editing mode, and you can now see it in full detail, select individual components of this part, expand the model tree to see their attributes using the "Center Graph" option and edit them if required, as shown in the lower image of Figure 10. If the quantity information of these objects has been calculated, this will also be displayed in the model tree.

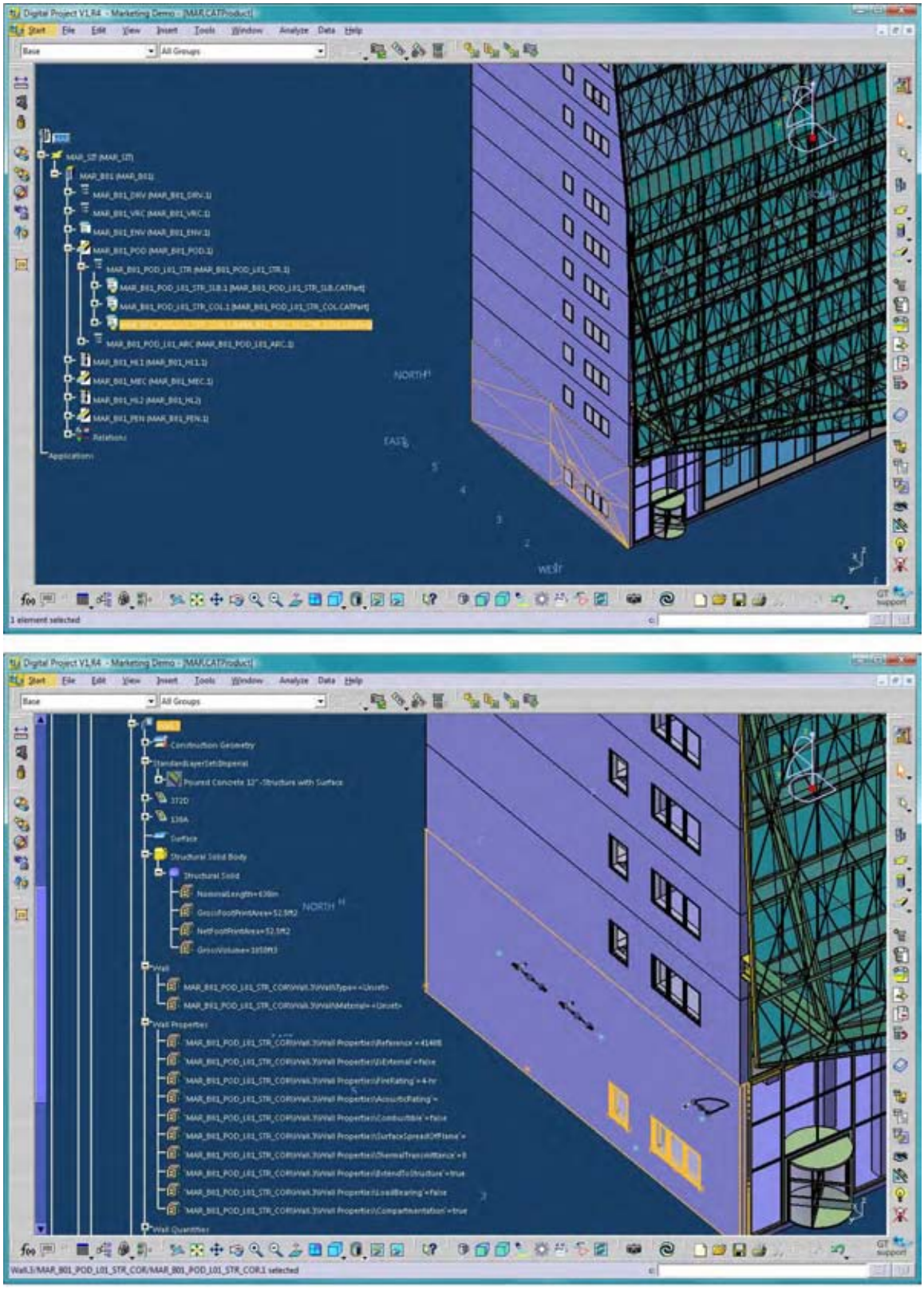


FIGURE 10. Viewing a part in the default CGR mode (top image) and subsequently double-clicking on it to open it in editing mode (lower image), where all its individual components are now visible in both the model view and the model tree.

It is this special CGR mode and on-demand loading of geometry that enables even a low-end computer to be used to view a large Digital Project model very easily and quickly, without running out of memory. Many parts can be opened for editing at a time, and they can be returned to the CGR mode at any time if the computer is running out of memory. The tessellation in the CGR mode does not make for the most attractive and pleasing of user interfaces, but it works as intended. Since the editing of the model may involve the editing of many of its individual part files, a simple Save command is not sufficient to save the changes. It requires a special Save Management command to be selected, which shows all the open files in the model and indicates the ones that have been modified (see Figure 11). These can now be saved, if required. Unfortunately, each modified file has to be saved individually; there's no option to save all the files that have been modified, which would have been quicker.

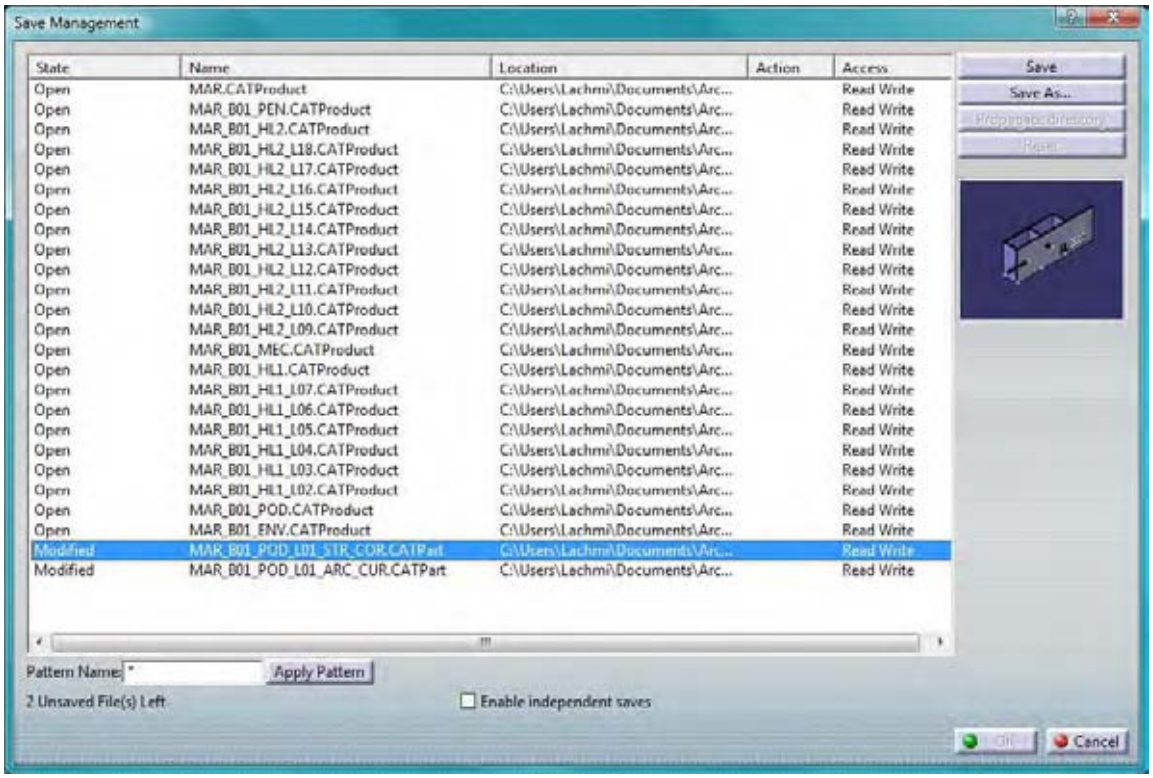


FIGURE 11. The Save Management dialog, showing all the open files in the project and indicating the ones that have been modified.

Other interface aspects of Digital Project that are noteworthy are the several model navigation tools and mouse-shortcuts available for navigating the model quickly and easily, the ability to hide/show elements by selecting them in the model tree or the model view, and a "Swap Visible Space" command that hides all visible elements and shows all the hidden ones. Also, the interface is relatively clean and uncluttered. On the flip side, some aspects of the interface are not very advanced. For example, even if Digital Project is already open, double-clicking on a Digital Project file in Windows launches another session of Digital Project, and given how long the application takes to open up, this can be quite an annoyance. You have to open up additional files from within the session using File > Open in order to avoid this. I also found that there was no way to isolate an element, part file, or lower-level product file by turning off the display of all the other objects, which would have been extremely helpful.

Functionality

Unlike other BIM applications where you can go in and start creating building elements such as walls, doors, windows, etc., right away, in Digital Project, you start by creating the "drivers" for the design. These include elements such as plan grids, elevation grids (typically referred to as "levels" in other applications), and the 2D shapes from which the 3D geometry is going to be derived. In fact, the creation of these is essential because all the building elements in Digital Project have to be modeled in relation to other elements, be it grid points, grid lines, 2D surfaces, or other 3D objects. You cannot, for example, model walls directly and interactively in the graphics window; the modeling happens only through the Wall tool dialog, through which you have to select, one by one, the "support" element which will define the path of the wall, the "top" and "bottom" limits of the wall, and the "to" and "from" limiting elements. An example is shown in Figure 12. As you can see, the Wall dialog also lets you specify offsets from the limiting elements, if required, as well as define the wall type and attributes from the Wall catalog.

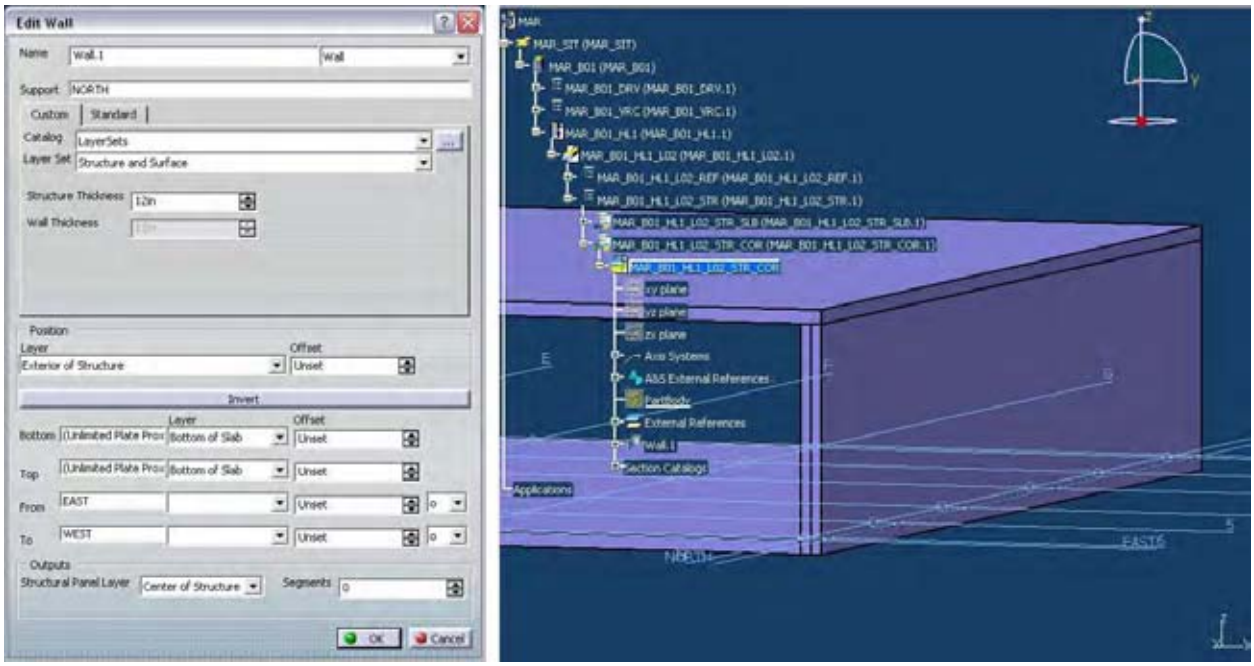


FIGURE 12. The settings in the Wall dialog that created the wall shown in the model. The North grid line was selected as the Support, the lower and upper slabs were selected as the Bottom and Top limits, and the East and West grid lines were selected as the From and To limits respectively.

Needless to say, this way of modeling is not very fluid, interactive, or user-friendly, particularly when compared to most modern-day design applications where you directly draw or model what you want on the screen. It can get extremely tedious to put together a complete building model where all the elements have to be modeled using dialogs rather than by directly drawing them on the screen. Even for inserting doors and windows in walls, there need to be predefined reference points that can be used for the placement or for specifying an offset from—you cannot just place them directly anywhere you want like you can do in other BIM applications.

Also, because all elements have to be created in reference to other elements, the process of modification is also not very interactive. You cannot simply select a wall and drag it to another position; you would have to move the support element that was used to create the wall. For the same reason, you cannot copy existing elements to create

new ones in other positions, as the reference information cannot be automatically deducted and will therefore be invalid.

It is possible, however, to model multiple walls, beams, and columns in one step, simply by selecting multiple elements as supports in their respective dialog boxes. An example is shown in Figure 13, where multiple columns were created in one step by selecting all of the column grid points shown in the top image. These points had to be specifically created at the grid intersections; they are not automatically inferred. As with walls, you would specify reference elements for the bottom and top limits of the columns. Similarly, multiple beams can be created by simply selecting multiple grid lines. For walls, this approach would work if multiple 2D shapes had already been created to define the placement positions of the walls. Also, when creating multiple walls, an Auto Connect option automatically appears in the dialog, which can be checked to automatically limit multiple walls to each other and clean up their ends. This ability to model multiple elements in one step does help to speed up the modeling process considerably, particularly once all the driver elements such as grids and 2D reference lines for the walls have been properly created.

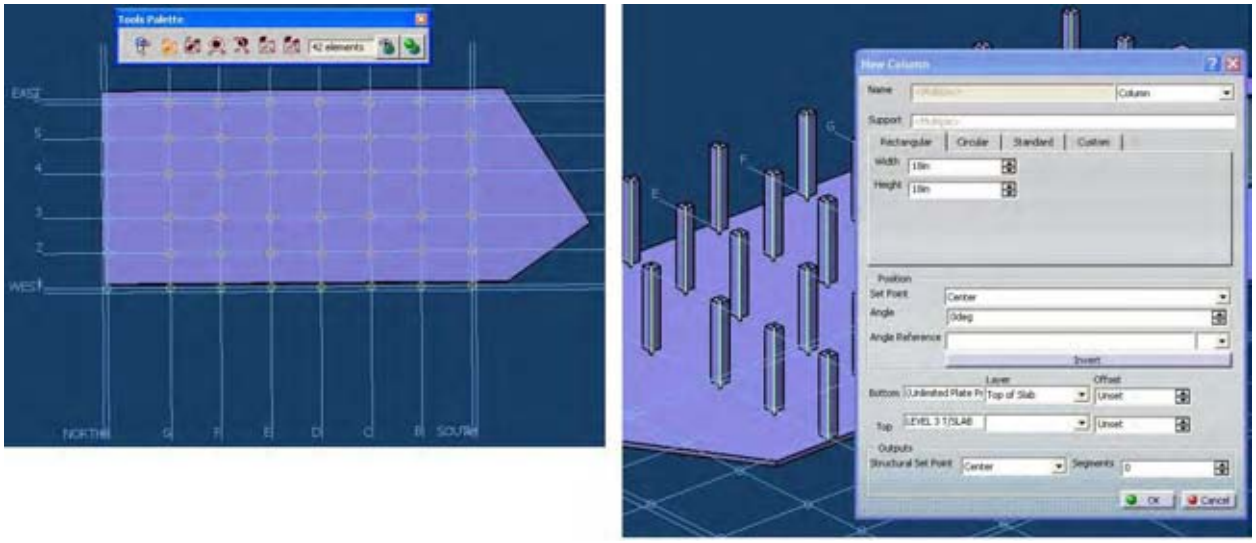


FIGURE 13. Creating multiple columns in one step by selecting multiple elements for the Support option in the Column dialog.

The real power of Digital Project really comes into play in the creation of the drivers and how they can drive the fully parametric nature of the building. You would typically start off by drawing a sketch to define the outline of the model. The Sketch mode in Digital Project is fascinating to work with, as it automatically applies constraints as you are drawing. For example, when you draw a rectangle, it is automatically created with horizontal and vertical constraints on its sides which will be maintained if any of the points is moved, as shown in Figure 14-a. Deleting one of the vertical constraints now allows the rectangle to be modified in such a way that maintains the constraints on the other three sides, as shown in Figure 14-b. In addition to these automatic constraints, many other constraints such as length, angle, co-linearity, parallelism, symmetry, and so on can be applied. Figure 14-c shows the same 2D shape with most of the directional constraints removed and some length, symmetry, angle, and coincidence constraints applied.

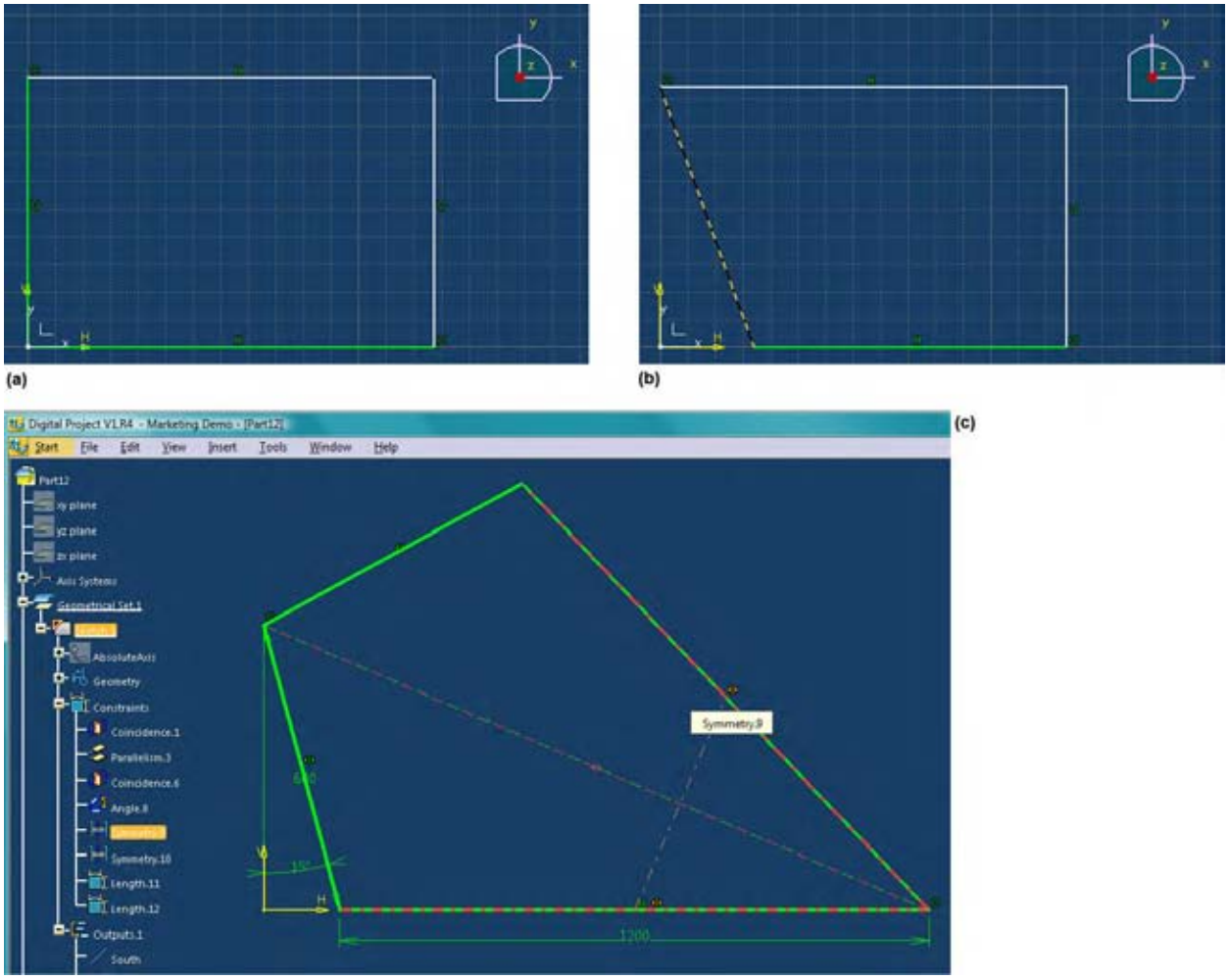


FIGURE 14. Using Digital Project's constraint-based sketching interface to create a 2D outline as the driver for a building model.

This outline sketch was subsequently used as the main driver to create the building model shown earlier in Figure 6 and below in Figure 15. It involved the creation of additional drivers such as elevation and plan grids, vertical lines of different lengths at the four corners of the 2D shape with a polyline connecting them to define the complex roof surface, and lines to indicate where the walls needed to be. All of the building elements such as columns, beams, walls, and slabs were then created with reference to all these drivers. The result is a fully parametric building model where any change to one of the constraints or drivers ripples through all associated elements. One example is shown in Figure 15, where the Angle constraint is changed from 15 to 30 degrees. As soon as the angle value is changed, all the affected parts of the model turn red, indicating that they need to be updated. Clicking on the Update tool starts the update process, which can take some time if the model is complex, as a lot of geometric calculations are involved. But at the end of it, all the individual elements of the model are fully updated based on the new angle and maintain their connections and relationships with one another. This level of parametric modeling is unique to Digital Project and cannot be found in any other BIM application. Thus, even though the model takes a lot longer to create because of the initial development of the drivers and constraints and the dialog-based way of modeling building elements, the payoff comes when changes need to be made. They are handled automatically by the application, maintaining all the rules and logic that have been built into the model.

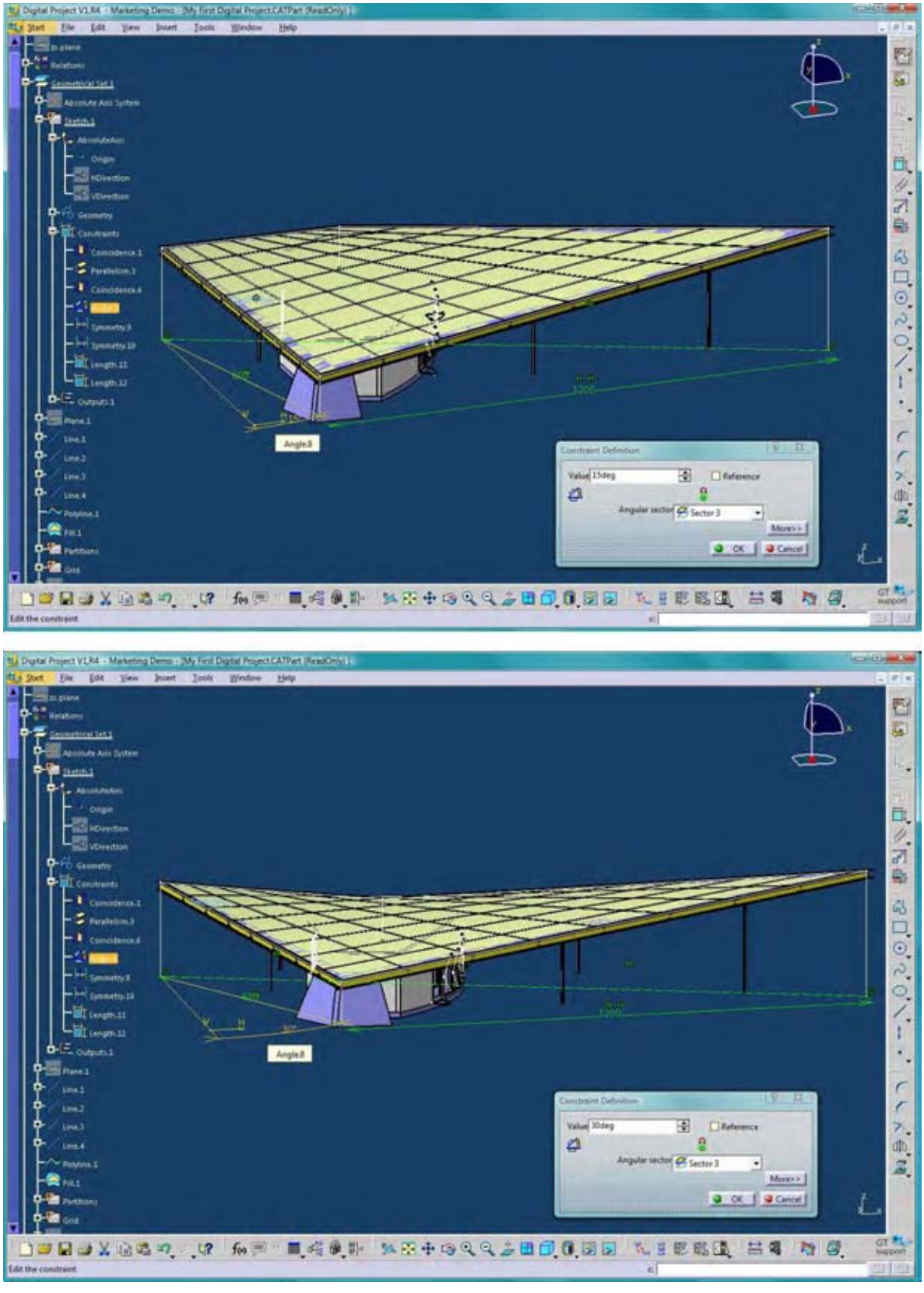


FIGURE 15. Changing one of the constraints of a Digital Project model automatically updates the entire model.

CONCLUSION

Digital Project is a very powerful and sophisticated tool with freeform modeling and parametric design capabilities that are unmatched by any other BIM application. Its file-based federated approach to modeling, along with the CGR visualization technology that loads geometry only on demand, allows it to handle projects of any complexity. Also, despite the fact that the model is broken down across multiple files, it still behaves as an integrated whole, so that any change ripples through all the affected components as though they were in one file. This is something that none of the other BIM applications with the federated approach, such as Bentley Architecture, have yet been able to achieve. Also, Digital Project's federated approach does avoid the problem of sharing one large file between a large, distributed project team, although it is does not work as well as the new server-based collaboration capability in ArchiCAD in enabling team members to work easily and quickly in real-time on modeling projects.

The two biggest limitations of Digital Project that stand in the way of its widespread implementation are its cost, which is considerably higher than the other BIM applications, and its complexity. It is not surprising that Gehry Technologies has positioned itself as a software+services firm rather than a software firm like the other BIM vendors—Digital Project is far too complex to be implemented without significant consulting help. Only very technology-savvy users would be able to learn it and use it properly—it is definitely not for the average user in an architectural firm. It is conceptually very different from any other building design or CAD tool, with a complete lack of fluidity and interactivity in its interface. It also has many, many more tools to master compared to the other BIM applications. This practically rules out Digital Project being adopted as the main BIM application for a firm, unless it's one like Gehry Partners that has already mastered the use of CATIA. Digital Project can certainly, however, be deployed as a complementary application for some projects, or parts of projects, that it can handle significantly better than the other BIM applications.

It must also be noted that there is very little information about Digital Project available on the Internet, apart from the Gehry Technologies website and the wiki that has been set up. There are no reviews, features, case studies on its implementation, or even frequent press releases put out by the company to highlight its progress and success stories. This indicates that the product has not gained a whole lot of traction, despite starting off eight years ago in 2002. While the Help documentation is very detailed, much of it comes straight from CATIA and is therefore very MCAD-focused. The introductory webinar series that is available online for free provides a brief overview of the application; however, its production quality leaves much to be desired. A comprehensive overview of the application was not even available on the Gehry Technologies website. The company itself was not very forthcoming to my repeated requests for information about Digital Project for the purpose of this study, conveying the impression of not being very professional or eager to promote the use of their software to a broader audience. On the other hand, the implementation study of Digital Project at Zaha Hadid Architects, which will appear in a later section, gave Gehry Technologies high marks for responsiveness, so its prognosis on this front remains somewhat mixed. Overall, Digital Project has many unique capabilities that are not available in any other BIM application, but these do come at the expense of complexity, scarcity of learning resources, and uncertainty regarding the quality of vendor responsiveness and support.

Comparative Evaluation

In this section, the evaluation results of all the BIM applications have been consolidated into tables for each of the six categories of evaluation criteria, enabling a quick side-by-side comparison of the applications for each criterion.

Application Repertoire	● = Good ● = Fair ● = Poor					
CRITERIA	Revit Architecture	Bentley Architecture	ArchiCAD	Allplan Architecture	Vectorworks Architect	Digital Project
Space Planning/ Programming	●	●	●	●	●	●
Conceptual Design/ Mass Modeling	●	●	●	●	●	●
Detailed Modeling	●	●	●	●	●	●
Schedules and Reporting	●	●	●	●	●	●
Quantity Take-off	●	●	●	●	●	●
Photorealistic Renderings	●	●	●	●	●	●
Animations	●	●	●	●	●	●
Real-time Model Exploration	●	●	●	●	●	●
Construction Documents	●	●	●	●	●	●
Coordination/ Clash detection	●	●	●	●	●	●
Fabrication	●	●	●	●	●	●

Intrinsic Nature and Capabilities	● = Good ● = Fair ● = Poor					
CRITERIA	Revit Architecture	Bentley Architecture	ArchiCAD	Allplan Architecture	Vectorworks Architect	Digital Project
Intuitiveness and Ease of Use	●	●	●	●	●	●
Ease of Project Setup	●	●	●	●	●	●
Information Re-Use	●	●	●	●	●	●
Modeling of Organic Building Forms	●	●	●	●	●	●
Automation of Tasks	●	●	●	●	●	●
Creation of Parametric Forms	●	●	●	●	●	●
Associative Behavior of Elements	●	●	●	●	●	●
Guarantee of Model Integrity	●	●	●	●	●	●
Availability of BIM Content	●	●	●	●	●	●
Customization Capability	●	●	●	●	●	●
Support for 3D Printing	●	●	●	●	●	●
Multi-Processing Support	●	●	●	●	●	●
64-bit OS Support	●	●	●	●	●	●
Cross-Platform (Windows, Mac)	●	●	●	●	●	●

Issues Specific to Large Firms	● = Good ● = Fair ● = Poor					
CRITERIA	Revit Architecture	Bentley Architecture	ArchiCAD	Allplan Architecture	Vectorworks Architect	Digital Project
Model Performance	●	●	●	●	●	●
Model Sharing Technology	●	●	●	●	●	●
Support for Distributed Workflow	●	●	●	●	●	●
Security and Access Controls	●	●	●	●	●	●
Performance Across WAN	●	●	●	●	●	●
Ability to Handle Large Projects	●	●	●	●	●	●

Interoperability	● = Good ● = Fair ● = Poor					
CRITERIA	Revit Architecture	Bentley Architecture	ArchiCAD	Allplan Architecture	Vectorworks Architect	Digital Project
Integration with Structural BIM Apps	●	●	●	●	●	●
Integration with MEP BIM Apps	●	●	●	●	●	●
Integration with Sustainability Tools	●	●	●	●	●	●
Integration with Estimating Apps	●	●	●	●	●	●
Integration with Constructability Tools	●	●	●	●	●	●
Electronic Publishing and Review	●	●	●	●	●	●
Range and Quality of Third-Party Tools	●	●	●	●	●	●
3D File Formats Natively Supported	●	●	●	●	●	●
Quality of API	●	●	●	●	●	●
IFC Support	●	●	●	●	●	●

Implementation	● = Good ● = Fair ● = Poor					
CRITERIA	Revit Architecture	Bentley Architecture	ArchiCAD	Allplan Architecture	Vectorworks Architect	Digital Project
Pricing/Licensing	●	●	●	●	●	●
Initial and Ongoing Training	●	●	●	●	●	●
Quality of Technical Support	●	●	●	●	●	●
Quality of Included Documentation	●	●	●	●	●	●
Free Online Learning Resources	●	●	●	●	●	●
Support Channel (Resellers, etc.)	●	●	●	●	●	●
Availability of Trained Staff	●	●	●	●	●	●

Vendor	● = Good ● = Fair ● = Poor					
CRITERIA	Revit Architecture	Bentley Architecture	ArchiCAD	Allplan Architecture	Vectorworks Architect	Digital Project
Current Market Position	●	●	●	●	●	●
Long-term Viability	●	●	●	●	●	●
Investment in R&D	●	●	●	●	●	●
Responsiveness to Feedback	●	●	●	●	●	●

Implementation Studies

In addition to the detailed evaluation of each BIM application that was accomplished by installing and working with it, further insights on the applications were gained by conducting implementation studies in firms around the world to explore how these applications have been deployed. Some of the firms that were studied use primarily one BIM application, whereas others have made it a point to implement multiple solutions to cater to diverse projects and client needs, despite the overheads involved. The size of the firms ranges from the 16 person firm, Miguelangel Gea Arquitectos, based in Spain to the global engineering giant, Jacobs, whose Building division includes over 3,000 people. Collectively, they serve to provide an inside look at how the applications are being used in actual practice, the challenges that are involved with implementing them, how training is accomplished, the level of support provided by the vendor, and the overall level of satisfaction with the application.

The order in which the firms appear in this section follows the order in which their primary BIM application evaluations have been presented in this report; so it starts with HKS Inc. that primarily implements Revit Architecture. Each firm study includes an image that shows the BIM implementation on one of their projects and is intended to provide an idea of the kind of work they are doing with BIM.

HKS INC.

HKS Inc. was established close to 70 years ago and now has over 1,100 employees in 25 offices worldwide. The firm was one of the early adopters of Revit, and has been implementing it since 2003. In addition to being firmly convinced of the value of BIM, HKS found several strengths in Revit that led it to standardize on Revit as its BIM platform: it was modern and easier to use compared to other BIM applications; it was a fully coordinated system so drawings were always true representations of the model; all schedules and tags were bidirectional and could be used to update the model; a large amount of data, including custom attributes, could be embedded into objects; and it was very easy to display object data in any desired form. Also, the fact that market leader, Autodesk, was behind it was a significant selling point in its favor.

In the years since its initial adoption, HKS has been using Revit extensively and on increasingly larger projects, which has caused it to test the limits of the software. It is experiencing several performance issues including a noticeable slowing down of operations such as opening and closing files, selecting objects, modification operations such as move, display regeneration, and so on. The 64-bit version of Revit that was introduced last year has helped in some ways—it at least allows large projects to be opened and worked on, whereas the earlier 32 bit version of Revit could not even open up the entire model for some projects. While the typical workstation at HKS is a 64-bit, quad-core machine with 8 GB of RAM, Revit cannot take advantage of the multiple cores as it does not yet support multi-processing. Also, Revit does not seem to be releasing memory quickly back to the computer after it is closed. Aspects such as these have made working with Revit a little problematic, and it can be especially frustrating for new users who are used to working with much smaller file sizes in CAD that usually represent only a sub-section of the project.

Also, the fact that Revit stores all its data in one gigantic file rather than structure its data more efficiently makes it more difficult to work with when it comes to model sharing and collaboration between distributed project teams. HKS has developed some workarounds to cope with this problem, which involves dividing up the model into 6 to 10 related worksets for organizational efficiency. It has developed a "BIM Organizational Guide" which serves as a

"best practices" manual for structuring the model into worksets. While experienced Revit users at HKS have become quite comfortable with partitioning their models in this manner, they still find it frustrating that they are forced to subdivide architectural models into separate models for performance reasons. The very nature of doing so splits what could have been a single database into multiple databases, which then have to be coordinated with each other. What makes it even harder is that the decision about whether to split a model and if so, where to split it, has to be made pretty early, even before the team knows a lot about the project.

While the transparent element borrowing feature in Revit has eliminated the need to consciously use worksets for collaboration—they are now primarily a means to organize the model into smaller, related categories to better manage the large file size problem as discussed above—HKS finds that collaboration in Revit across distributed offices is still problematic because of the large file sizes, which cannot be shared across a WAN without some latency. It has recently started experimenting with using Windows Remote Desktop on a few Revit projects. This allows the remote users to work on a central file in another office without having to actually transfer model data over the WAN—the only data being transmitted over the WAN are the mouse clicks, screen images, and keyboard strokes. This remote use of Revit is seeing some success and most users are happy with it, despite the latency of the screen refresh, which can be choppy when panning and zooming, depending on the distance between offices. But most users find this a relatively minor annoyance as compared to the long open/save/reload times when synchronizing their local copies of Revit files with the central files because of the large file sizes.

Another aspect of Revit that has been somewhat problematic for HKS is Revit content, despite the plethora of manufacturer-specific Revit content available online from Autodesk and other third-party content developers. HKS has found that this content tends to be over-detailed and overloads the already large Revit model. Therefore, it has dedicated significant time and resources—three full-time employees—to developing its own BIM content with the right level of detail that it needs. These content developers make general content which is used on a majority of HKS projects; they also help educate project team members on how to customize that content, when required, using Revit's Family Editor.

With regard to training, HKS has not found the built-in documentation within Revit very helpful, but it is availing of the large amount of training content that Autodesk has made available online for its subscription customers. HKS also made a conscious decision to handle its own training and has developed a lot of in-house training content focused specifically on how Revit is used at HKS, in contrast to the Autodesk material that provides generic training on how to use the different tools. HKS has a full-time person dedicated to training who travels to all the offices to train both new and existing Revit users. This is supplemented with frequent brown-bag lunch sessions featuring HKS users that are experts in specific Revit features.

The overall feeling at HKS with regard to Revit is very positive for the most part, especially in comparison to CAD. Users definitely do not want to go back to the old CAD-based way of working. Yet, there is the feeling that Revit is not yet a fully mature program and still has a lot of kinks that Autodesk needs to iron out. The Structure and MEP applications of Revit are lagging even further behind in maturity than Revit Architecture. However, HKS also appreciates that significant advancements are being made in these two discipline-specific applications with each release—this is especially true for the MEP application in the new 2011 Revit release.

HKS would like to see Revit, first and foremost, tackle its most critical problem of unmanageable file sizes, as well as improve speed and efficiency through better data structuring and incorporation of technological advances such as multi-processing. Other key needs include enhanced collaboration capabilities to make them more fluid and

real-time, and improved interoperability so that different disciplinary models created using different BIM applications can be easily shared back and forth between multiple offices—the IFC format is not good enough.

HKS has invested a lot of time and effort in its Revit implementation and would like to see it succeed. While it would like to see Autodesk respond to its needs more quickly, it understands the constraints faced by publicly traded software vendors who have the concerns of stockholders to balance with desires of their installed base of customers, along with the imperative to gain new users. It also appreciates features such as transparent element borrowing in Revit that were specifically developed in response to requests from many large firms, including HKS. In recent months, Autodesk has increased its level of responsiveness and has initiated a Large Team Workflow project in which HKS and other LFRT firms have been invited to participate. This seems to represent a sincere effort by Autodesk to better understand and respond to the needs of large firms and Enterprise License customers, and is greatly welcomed by HKS. The firm also appreciates the significant improvements made by Autodesk in each new release of Revit, even if they do not directly tackle the collaboration and workflow issues faced by the large firms.

Over and above the performance issues in the software, one of the biggest challenges HKS is facing in its BIM implementation is in getting its designers to use Revit. Many view Revit as a production tool, and they are not convinced that Revit can function as a pliable design tool. They also feel that the application is bulky and complicated, in contrast to say, an application like Google SketchUp which is very popular and widely used at HKS. Autodesk needs to listen more closely to this user group, not just at HKS but across the entire industry, and address their concerns.

HKS' Revit implementation of the Parkview Regional Medical Center in Indiana. (Courtesy: HKS)

JACOBS GLOBAL BUILDINGS NORTH AMERICA

Jacobs Engineering Group Inc. started in 1947 primarily in the process/plant area, and is now a publicly traded company with a workforce of over 55,000. It was the #1 ENR design firm for 2008-2009. Its markets include aerospace and defense, automotive and industrial, buildings, energy, environmental, infrastructure, oil/gas,

pharmaceutical, bio, refining, and technology. Jacobs' Buildings business unit, known as Global Buildings North America (GBNA), has over 3,000 people distributed in 23 offices throughout the US. It offers the full breadth of building services including planning, architecture, engineering, construction management, program management, and design-build to a diversified base of public and private clients, domestically as well as around the world.

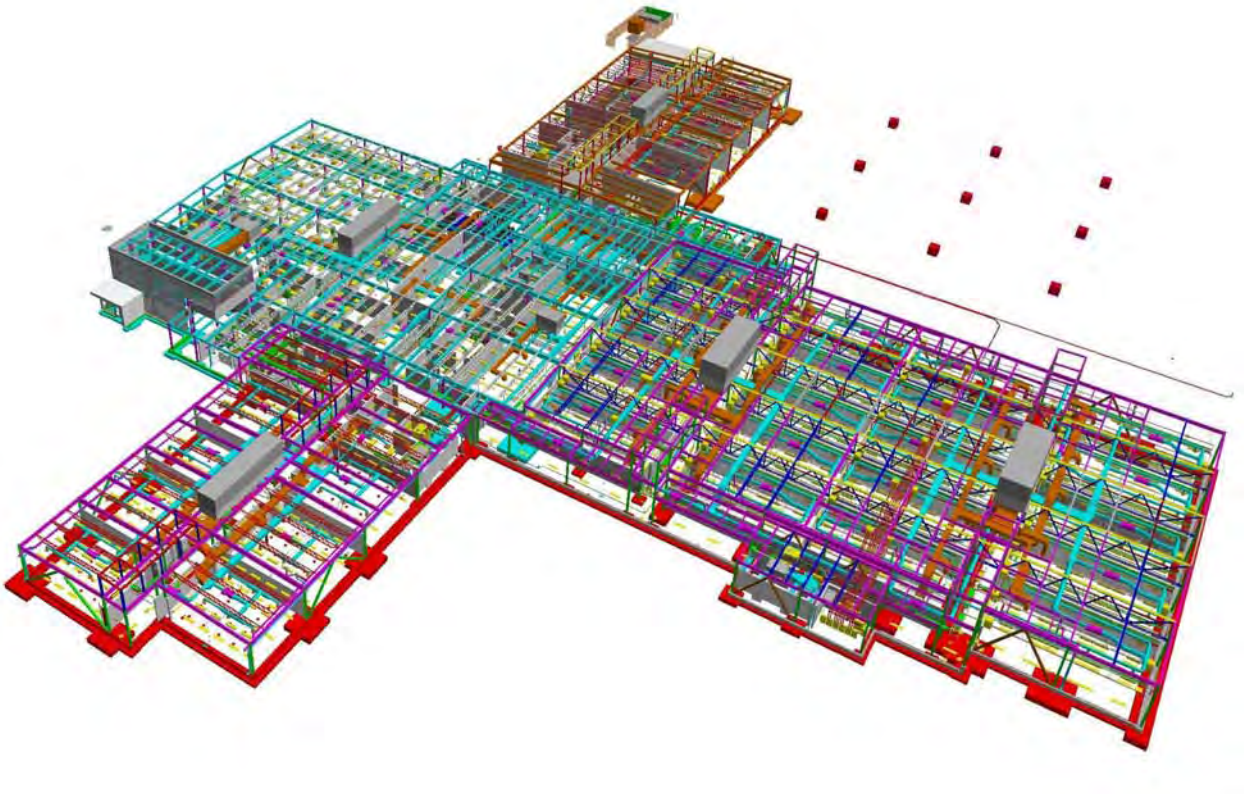
In the CAD era, Jacobs GBNA was primarily using Bentley's MicroStation as opposed to AutoCAD, and was an early adopter of Bentley's object-based design applications—known then as TriForma—in the early 1990s. As BIM technology began to develop and evolve, Jacobs GBNA was very aggressive in adopting it. Not only was it very comfortable with Bentley's BIM solutions, given its long history with Bentley, it also recognized the unique strengths of Autodesk's Revit platform and has implemented that as well. It has licensing arrangements with both Autodesk and Bentley that allow it virtually unlimited use of all their BIM applications. Jacobs GBNA is a firm believer in the need for large firms to work with multiple platforms, and tries to keep the ratio of its Bentley to Revit BIM implementation at 50-50. At the moment, its Bentley implementation is slightly higher than its Revit implementation because of the specific requirements of some of its projects and clients. BIM is used on all projects, and all the way through to construction documentation, on both the Bentley as well as the Revit platforms. The only time 2D CAD applications such as MicroStation and AutoCAD are used is when the 2D deliverables created using BIM need to be checked for the satisfaction of some specific drawing standards or any other 2D-based requirement.

Being an A/E firm, Jacobs GBNA uses all the multi-disciplinary BIM applications available on both the Bentley and Revit platforms. Collaboration is critical to the firm's workflow, and it uses Bentley's ProjectWise for model-sharing and managing distributed project workflows. Bentley's federated approach lends itself much more readily to splitting large projects up for multiple team members to work on, and ProjectWise becomes a very effective tool for managing all the multiple files that make up a project. Jacobs GBNA is in the process of determining if ProjectWise can also be used to manage collaboration and distributed workflows in Revit. This is because the built-in collaboration capabilities of Revit are problematic, with the large file sizes making it difficult to quickly synchronize users' local copies of the model with the central model. The collaboration limitations in Revit has led Jacobs GBNA to adopt a "best practices" policy of keeping individual disciplinary work within a single office, so that it is easier for multiple team members within a discipline to collaborate on a project. Although this is not really required for Bentley projects, Jacobs GBNA tries to follow the same rules for both platforms. The different disciplines, however, are typically located in different offices, and for Revit projects, this usually means some latency in sharing disciplinary models between the different groups.

Since it implements both platforms, Jacobs GBNA is in a position to take advantage of the main strengths of both. For Bentley, this is the ability to work with large projects and collaborate more easily, both within a discipline as well as across disciplines. For Revit, Jacobs GBNA is able to enjoy the benefits of its single model approach, which allows for automation across the project of tasks such as Construction Document setup. Of course, Jacobs GBNA is also experiencing the limitations of both platforms—for Bentley, it's the lack of automation in the Construction Document process, while for Revit, it is the inability to handle large, complex projects across Jacobs' multiple offices. However, Jacobs GBNA finds both Bentley and Autodesk well aware of these limitations in their respective applications and is working with the vendors to find solutions to them. Also, by virtue of its long history and expertise in Bentley's solutions, it does not find them particularly complex. For example, it has streamlined and standardized its BIM project setup in Bentley to such an extent that it now takes a minimal amount of time to set up a new project. Thus, the complexity of Bentley's solutions and the other limitations of its federated approach—such as complicated project setup and no automatic change management across files—that new users would encounter and would likely be daunted by are not an issue for Jacobs GBNA at all.

BIM training at Jacobs GBNA is primarily achieved by in-house experts providing project-based, just-in-time training to project teams at different stages of the design project, enabling designers to learn BIM hands-on in the process of applying it to an actual project. On many projects, the team members have no prior BIM experience or training, and this project coaching technique has proven to be very successful. If required, the project training is supplemented with tool-based training provided by the individual vendors, and these are arranged by local offices on an as-needed basis.

In addition to BIM, Jacobs GBNA uses an extensive array of analysis tools for structural and MEP design as well as for energy analysis. While the engineering analysis tools work very well, the energy analysis tools are somewhat problematic as there is not enough published information outlining the best practices for modeling to make them work. Overall, the field of energy analysis, particularly that which is supposed to work with BIM models, is not yet mature and Jacobs GBNA is going through a lot of trial and error to make it work. While the IFC effort is commendable, it is still inadequate for solving the interoperability problems in the AEC industry. For model review and collaboration, Jacobs GBNA makes extensive use of Navisworks and also finds Bentley's new Project Navigator very powerful. It is also very intrigued by Bentley's new "i-model" concept. Overall, it is glad to be in a position where it can take advantage of such developments, as well as explore the use of advanced technologies such as GenerativeComponents that integrate with Bentley solutions.



Multi-disciplinary model of Jacobs' USACE BCTC Program Prototype, created using Bentley's BIM solutions. (Courtesy: Jacobs GBNA)

QUATTROCCHI KWOK ARCHITECTS

Quattrocchi Kwok Architects (QKA) is a 25 year old, 50 person firm based in Santa Rosa, California, which primarily works on school projects. The firm decided to make the switch to BIM in 2005, as it found that BIM was a better way of doing architectural design and it wanted to be at the forefront of the BIM movement rather than lagging behind. Prior to this, it was using AutoCAD for its 2D work. To select a BIM solution, it defined a list of criteria that were important to the firm and conducted an internal evaluation of the top three BIM solutions—Revit Architecture, Bentley Architecture, and ArchiCAD—against these criteria. ArchiCAD came out on top in this internal evaluation, based on the criteria they had identified. As part of the evaluation, QKA also invited representatives from the three vendors to visit their firm and present their solutions. Even in this aspect, ArchiCAD came out on top as Graphisoft was the only vendor whose presentation was specifically focused on addressing their concerns, as opposed to the canned presentations that were given by the other vendors. From QKA's perspective, this was also a test of customer service, and to this day, it continues to find Graphisoft very responsive to its requests and needs.

The main strengths of ArchiCAD according to QKA are its range of capabilities, ease of use, flexibility, licensing structure, and customer service and support. It has found ArchiCAD to be a comprehensive BIM application with full-fledged documentation capabilities—95% of its projects are now fully done in ArchiCAD, including construction documentation, without reverting back to AutoCAD for the 2D work. It has 25 ArchiCAD licenses and has reduced its AutoCAD licenses to a handful, primarily for some civil, landscape, and electrical work. In contrast to ArchiCAD, which had been around for so many years and was a mature application, Revit seemed relatively immature. Bentley Architecture, in contrast, seemed mature as well as capable and robust; however, QKA also found it dense and hard to learn, making it too big a barrier for the firm to transition to BIM. One aspect of ArchiCAD that really stood out for QKA was its flexibility—there were lots of ways to do things and the modeling interface was not as constrained as in Revit. Also, unlike Revit, ArchiCAD still uses layers, and QKA finds that this provides many more ways of classifying elements and controlling their display and representation styles. The service and support has continued to be excellent, both by Graphisoft as well as the local ArchiCAD reseller, Archvista.

The revolutionary new BIM server-based collaboration capability that was introduced in ArchiCAD 13 has only served to re-affirm for QKA that ArchiCAD was the right choice for them. Projects can now easily be worked on simultaneously by 10-15 people. The new collaboration capability, along with the recent 64-bit support and multi-processing capability, has now made it possible for QKA to handle even very large projects easily, with no performance issues or the need to break up the model into parts. One of their largest projects to date has been an 80,000 sq ft building, for which the ArchiCAD model, which included the full construction documentation set, was 300 MB. The firm did not encounter any performance issues even for this project.

Another recent innovation in ArchiCAD that has been greatly appreciated by QKA is the built-in energy analysis tool, EcoDesigner. QKA finds this much superior to Green Building Studio (GBS), which they were using prior to the introduction of EcoDesigner. They found that GBS was making a lot of assumptions about the design that were difficult to see, let alone edit, and it provided them with very precise results that were very questionable. In contrast, EcoDesigner allows the assumptions that it uses for its energy analysis to be edited and provides results that seem to be accurate and believable. Thus, EcoDesigner has definitely filled the need the firm had for preliminary stage energy analysis of the proposed design. For more specific analyses such as daylighting, QKA continues to use other applications such as Ecotect.

The fact that ArchiCAD is a single disciplinary application rather than part of a multi-disciplinary platform like Revit or Bentley is not perceived by QKA as a serious limitation. It uses the IFC format to exchange model information with its structural and MEP engineers, who are currently using Revit. While the IFC format does not work perfectly, QKA has figured out what options to set for the IFC import/export to get a workable result and knows what anomalies to expect. It has not started using Navisworks yet for design coordination, and instead relies on bringing in the different models in ArchiCAD for visual inspection. While the firm does share its models with the contractor, these are not used for construction; this is because QKA's main focus area—school design—still follows the traditional design-bid-build process where the 2D construction documents are used for construction. The clients in this field are also still relatively unsophisticated and are not even aware of BIM or its benefits, let alone demanding that a specific kind of BIM application be used.

Despite the excellent quality of ArchiCAD's training content and online resources, QKA does not actually rely on these a lot. All new employees are sent for a basic 2 day training course to the local ArchiCAD reseller. This is supplemented by regular in-house training seminars that are focused specifically on how ArchiCAD is used within QKA—this information is also captured in a 200 page internal manual that is kept updated with new releases. The company also hired an external consultant initially for providing indepth training to its core technical people and for helping to set up the standards within ArchiCAD based on QKA's workflow and processes.

Overall, QKA is extremely happy with its choice of ArchiCAD for its BIM implementation. The only aspects it can see that could potentially be improved in ArchiCAD are better interoperability using the IFC, improved integration with other disciplinary applications such as Revit Structure and Revit MEP, a more visual environment for developing parametric content in ArchiCAD as opposed to scripting using GDL (which only a few advanced users in the firms have learnt), and the availability of more manufacturer content built specifically for ArchiCAD.

The American Canyon High School project designed by QKA using ArchiCAD. (Courtesy: Quattrocchi Kwok Architects)

MORRIS ARCHITECTS

Morris Architects was established close to 70 years ago and now has over 200 people in three locations, Houston, Orlando, and Los Angeles, working on domestic as well as international projects. The firm has an interesting history with regard to its BIM implementation, which reflects the diversity of the firm and the work that it does. The BIM implementation began as early as in 1990 in the Orlando office, with what was then known as Autodesk Architectural Desktop (ADT), an object-based architectural design software built on top of AutoCAD. To this day, the Orlando office continues to use ADT, now known as AutoCAD Architecture (ACA), despite the fact that its BIM capabilities are not as comprehensive or sophisticated as the other BIM applications. The Orlando office also hosts the firm's landscape design group, which prefers the Mac platform and uses Vectorworks, specifically its Landmark application for landscape and site design. It however, does not use Vectorworks Architect as a BIM application.

In contrast to the Orlando office, the Houston and Los Angeles offices bypassed the use of ADT/ACA altogether and moved from implementing 2D design in AutoCAD to adopting Revit for their BIM implementation 5 to 6 years ago. Of late, they have also started using Revit as a design tool rather than simply for post-design development and documentation. Morris teams using Revit have seen great improvements in workflow, information gathering, coordination, communication, visualization, and communication. BIM is enabling the design of buildings that are more responsive to client needs. This positive experience has lead to a firm-wide commitment to using BIM on every project.

While the overall experience with Revit as a BIM tool has been generally positive, it has required a major investment in infrastructure and still runs into limitations with large files. Morris Architects has spent thousands of dollars trying to manage these issues and make Revit work, including investing in more high-end computers with more memory, as well as WAN acceleration technologies such as Riverbed. Still, collaboration on a large project is far from fluid in Revit. Also, Autodesk has not been very responsive to the problems it is facing, and support requests are not met fast enough. There have been instances when Autodesk has advised Revit users in the firm to "fudge" something in response to glitches in the software, which has further undermined their confidence in Autodesk and in Revit. Autodesk also does not do an adequate job of communicating potential problems and changes in upcoming releases; for example, the DWF writer that was available for the 32-bit version of Revit is not yet available for its 64-bit version to which Morris Architects has upgraded, leaving them without a working process now to share models in the DWF format with consultants and clients.

Given all these problems, particularly those related to the file size and collaboration process in Revit, Morris Architects was very interested in the new model server-based collaboration technology introduced in ArchiCAD 13, which motivated them to take a detailed look at this application as an alternative BIM solution. So far, they have been very impressed with the collaboration technology in ArchiCAD, especially the integrated instant messaging capability and the color-coding, which makes it possible to immediately see who is working on what part of the model. The fact that this technology comes free with the application instead of being charged for separately is an added selling point in its favor. The firm was also very happy with the support that was provided by Graphisoft in their initial exploration. Another plus point for ArchiCAD was better IFC support as compared to Revit—based on their work exchanging data between different BIM applications, Morris Architects found that the results of ArchiCAD's IFC import/export were superior to Revit, despite the fact that both applications have been certified for IFC support by the IFC developers. The fact that ArchiCAD has better integration with Vico's construction software is also appealing to Morris Architects, as some clients are asking for the use of Vico. All of these factors have added up to make ArchiCAD a very compelling BIM solution for Morris Architects, and the

firm is now looking to test-drive the application on an actual project and take it all the way through with ArchiCAD.

The openness to implementing ArchiCAD, despite already implementing Revit, serves to demonstrate a key aspect of Morris Architects' approach to technology implementation—they firmly believe that large firms should not lock themselves down to one application. In particular, given the diversity of most large firms—Morris Architects has 12 principals and 7 different studios—it is important to allow different groups within the firm the flexibility of implementing the application that works best for them rather than forcibly standardizing on one application and one approach. This also makes sense from a business perspective, as different clients have different needs and different technology requirements. For example, Morris Architects has clients who still require the use of AutoCAD Architecture, and it recently had two clients asking for Bentley BIM implementation. Thus, being proficient in multiple platforms will better enable the firm to meet the demands of different projects and different clients, as well as the individual needs and preferences of its employees.

Preliminary ArchiCAD model of the headquarters of a broadcasting company in Vietnam, the first created by Morris Architects with their initial exploration of the application. (Courtesy: Morris Architects)

This open philosophy also makes Morris Architects a believer in interoperability rather than integration, and it does not find the single-disciplinary capability of ArchiCAD particularly problematic. It believes in the use of "best of breed" tools for different tasks and disciplines, and often works with consultants who are not on the Revit platform. At the same time, it does acknowledge that the IFC does not work as well for interoperability as required in order to enable a seamless flow of information from one application to another. In contrast, Navisworks is emerging as a popular solution for consolidating different disciplinary models for design coordination and review, and it greatly diminishes the need for all disciplines to be working on a common platform. Morris Architects is

currently having more success collaborating with structural engineers using BIM; however, the MEP side is more problematic as many MEP engineers are not yet up to speed on BIM. With regard to energy analysis, Morris Architects finds none of the existing tools adequate, including Ecotect or EcoDesigner, as they require the model to be created in a specific way, which is not easy to do and requires some specialized knowledge of energy analysis. For other downstream uses of the model, Morris Architects finds most contractors using Vico for quantity-takeoff and is quite happy to provide its model to them for convenience.

On the training front, Morris Architects is similar to other firms by starting out employees new to BIM with a two day training session provided by the vendor or reseller, which provides them with a general know-how of the application and how to use the different tools. This is following by in-house customized training sessions that are more focused on how the application is used within the firm. Morris Architects makes uses of the training resources provided by Autodesk as well as other vendors and is pleased with their overall quality.

KING & KING, ARCHITECTS LLP

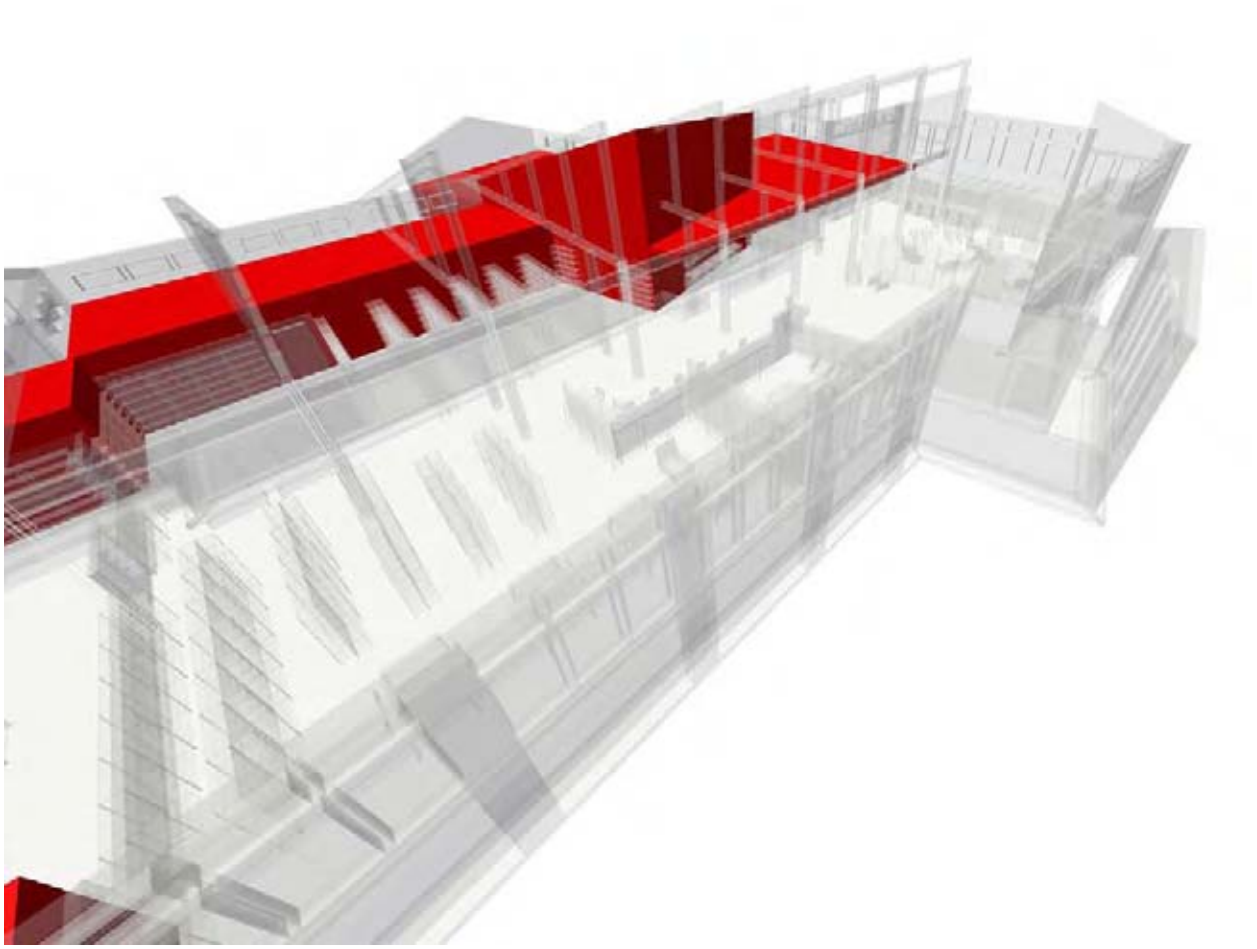
Established 143 years old, King & King, Architects LLP is a regional firm of 75 people serving the Upstate New York area and has the distinction of being the oldest architectural firm in the state. It specializes in schools, higher educational campuses, healthcare facilities, medical universities, and smaller commercial and mixed-use projects. The firm started using Apple's Macintosh platform when computers first began to be used in architectural practice and continues to remain a Mac-based firm to date. In the 1990s, it was using a Mac-based 2D and 3D object-oriented application called Architrion for its design and drafting needs. In 2000, following the sale and subsequent demise of Architrion, King & King evaluated the two main Mac-based architectural design applications that were available: ArchiCAD and Vectorworks Architect. At that time, it found ArchiCAD too complex for its needs—the application required a steep transition from 2D to 3D, which many of the firm's users were not comfortable with. In contrast, Vectorworks was found to be user-friendly, easier to learn and use, not as complex, as well as half the price of ArchiCAD and other comparable applications. While it allowed users to derive the benefits of its object-based capabilities, it did not impose a strict 3D way of working and was a lot more flexible. It was also very well supported with good training. Therefore, King & King chose to implement Vectorworks Architect as their primary design application, and continue to use it in this capacity even today.

The transition from 2D to 3D design has been a gradual one for the firm. About 6 years ago, they starting using Vectorworks' object-based tools for walls, doors, windows, and so on, and while this was primarily being done in 2D, it was still object-based and allowed them to take advantages of features such as automated production of schedules. Since the last two years, an increasing amount of 3D information is being added to the project. However, the firm has not completely transitioned to the BIM way of working, where all of the information is added to the model and deliverables such as drawings are fully derived from the model. Only a few smaller projects have been implemented in this "fully BIM" way—for all the others, the plans are derived from the model, but sections and elevations are created separately in 2D and do not stay coordinated with the model. According to King & King, this is not due to any kind of limitations within the software; it is more due to the business and economic climate in the part of the country where it operates. Not many clients there are buying into the use of BIM, many consultants are still behind on the use of BIM, and many of the firm's users that are comfortable with designing the 2D way are not eager to change how they work.

However, King & King does experience and acknowledge one significant limitation in Vectorworks—the lack of a collaboration capability that would make it easier for multiple team members to work on a project. This forces

them to divide up the model into multiple models if more than one person is working on a project, which then loses on the benefits of being fully contained in a centralized BIM model. For example, on a recent multi-tower hospital project that has a large project team, each level of the building has been created as a separate model so that it is easier for the different team members to work on the project. A feature such as ArchiCAD's server-based collaboration or even Revit's worksharing capability is greatly missed by King & King in Vectorworks Architect.

Apart from this, the firm is very happy with Vectorworks' progress as a BIM application and the features that are added in every new release than enhance its BIM capabilities. The firm also makes extensive use of its plug-in module, Renderworks, for creating photorealistic renderings from the model. They find the vendor, Nemetschek North America, very responsive to support calls and feature requests, which helps them greatly. Another benefit of using Vectorworks Architect is the ease of training. Only a few of the key technology people receive professional training from the vendor on an ongoing basis to keep up with the new features and BIM capabilities—the rest of the staff is trained in-house by these people, who develop a customized version of the training based on how the application is used at King & King. This reliance on in-house training alone for most of the staff helps reduce training costs considerably and would not have been possible for a more complex BIM application.



Preliminary design of the Swan Library in Albion NY designed by King & King using Vectorworks Architect. (Courtesy: King & King Architects)

At this point, therefore, Vectorworks Architect is working for King & King perfectly, and they have invested a lot of time and resources into it, so they would prefer to stick with it rather than be forced to adopt any other BIM application. The firm has recently had clients who are BIM-aware and asking for a specific BIM application such as Revit to be used; so far, it has succeeded in educating them about aspects such as interoperability and the IFC format, which makes it possible to use any BIM application to create the same end-product, which is a BIM model of the design. Thus, King & King, just like Vectorworks' developer Nemetschek North America, is a strong believer and supporter of the IFC format. It has been testing its use by importing IFC models—including its own models from Vectorworks Architect and consultants' models when available—into Solibri's model checking application for clash detection. It is also starting to look at energy analysis tools such as Ecotect that can work with the IFC format. Going forward, it does not rule out the possibility of using another BIM application in addition to Vectorworks Architect, but for now, it finds this application more than sufficient to do BIM as well produce the necessary documentation for building design.

MIGUELANGEL GEA ARQUITECTOS S.L.P.

The studio-firm Miguelangel Gea Arquitectos (MGA), S.L.P based in Seville, Spain, was founded by Miguelangel Gea in 1977, and includes 16 professionals specializing in architecture, urban planning and interior design. Despite being a relatively small firm by US standards, it works on a wide variety of projects of different types and sizes, all located in Spain, with a particular specialization in large tourist resorts. The firm makes a special effort to update the know-how of the team and continuously adapts itself to technological changes, new industry standards, and construction systems, making use of modern IT to elaborate and present its projects. It started implementing BIM in 2005, and can be considered a pioneer in this regard as most firms in Spain are still using 2D CAD applications such as AutoCAD for design. MGA was also using AutoCAD prior to BIM, but today it uses AutoCAD only for checking incoming 2D plans from collaborating firms. For its own work, it uses BIM all the way through.

The BIM application that MGA chose to implement when it started in 2005 was Nemetschek's Allplan, and since then, the firm has invested a lot of time and resources into making it work. There were several aspects of Allplan that appealed to the firm when it started looking at which BIM application to implement. These include the tablet-based sketching application, Allplan Sketch, which is fully integrated with Allplan, and allows initial sketches and drafts to be quickly shared with clients as well as digitally edited and used immediately in the BIM application to jump-start the design process. Another factor in Allplan's favor was its bidirectional integration with Cinema 4D—also a Nemetschek application—for creating sophisticated renderings directly from the model. MGA also appreciated Allplan's user-friendly interface and its use of wizards that speed up the creation and editing of elements. The firm found that it took about a month for new users to get up to speed with the application, and they are able to handle their own training internally without paying for professional training from Nemetschek. The switch from CAD to Allplan change didn't present any problems even for its 60-year-old employees!

Since the firm often works on large projects, teamwork was a very important consideration, and it is well facilitated by Allplan's Workgroup Manager, which allows multiple team members to easily work on the same digital building model. It also handles the central administration of projects, which ensures that all the projects on all the computers can be accessed and edited directly from every workstation. The distributed file structure of Allplan lends itself easily to the creation of large projects, and there have been no performance issues with the application. Some of the largest projects that MGA is working on with Allplan include a 400 room hotel of 60,000 sq. m. (650,000 sq. ft.), and a large tourist resort on a 135-hectare island which includes 300 vacation homes, two hotels, and other amenities such as a clubhouse, sports arena, harbor, and so on. MGA has spent some time developing a

system for efficiently organizing a large project for better team collaboration, and this has been very effective in enabling it to work as easily on large projects as on small ones. With regard to collaborating externally with structural and MEP engineers, landscape architects, and others, none of these disciplines are still using BIM, so MGA is forced to use 2D drawings to work with them. However, it does make extensive use of Adobe's 3D PDF—which can be directly created from Allplan—to share model information with other design specialists as well as clients.

On the downside, the main limitation of Allplan has been poor service and support by Nemetschek in Spain in general. There were a few other firms in Spain that bought Allplan but are not implementing it because they have not been adequately supported by Nemetschek in showing them how to use it. Another critical limitation is that Allplan does not yet integrate with analysis and cost planning tools that are popular in Spain such as Presto and Cype. Nemetschek has provided this kind of integration with tools in Germany, where it is headquartered, and MGA thinks it should also do the same for other countries like Spain where it is selling Allplan.

The tourist resort on an island off the coast of Spain being designed by MGA using Allplan Architecture (Courtesy: Miguelangel Gea Arquitectos)

Apart from these limitations, MGA finds Allplan, on the whole, a well-designed application that has all the functionality it needs, and it is very satisfied with its choice of BIM application. It did take the firm a while to get Allplan running efficiently, but now that it has streamlined its BIM processes and workflow with Allplan, it has no plans to look at any other BIM application, let alone think about switching to a different one. With the use of Allplan, the firm is able to execute projects today in a timeframe and with employee capacities that would have been unthinkable three years ago. Allplan's integrative concept has made the day-to-day work easier for the firm's designers and has given them a lot of creative freedom, as they no longer need to follow a rigid sequence of work steps—they start with the 3D model and visualizations and then create detailed 2D drawings. They can also react much more quickly and flexibly to design changes. The use of Allplan and CINEMA 4D has also given MGA a competitive edge by enabling it to plan a building within the shortest space of time and create high-quality, photo-realistic visualizations that can be shared with clients early on to get their feedback.

ZAHA HADID ARCHITECTS

Zaha Hadid is one of the world's most famous contemporary architects and has won numerous awards, including the Pritzker Prize in 2004. She established her practice in London in 1980, and since then, it has grown to over 400 people, of which close to 300 are based in the London headquarters while the rest are in offices in various parts of Europe and Asia, where the bulk of the firm's projects are located. Although the firm has done some projects in the US, including the Eli and Edythe Broad Museum coming up at Michigan State University, it does not have a US office yet. The size of the firm has grown ten-fold over the last 8 to 9 years, which has been quite challenging, both from a management as well as technological perspective.

The firm has a relatively flat hierarchy with two partners, a handful of directors, and close to 30 associates, who manage one or more projects. The different associates head groups that have their own preferences when it comes to design processes, workflows, and the digital tools that they use. This means that a large number of tools and techniques are used in the firm. About 30% of the work is done entirely with Autodesk Maya and Rhino, with AutoCAD for the 2D work, without the use of any BIM application at all. This would typically be for smaller projects such as villas. The rest of the work is done using BIM, but with different solutions. A large part of the BIM work, making up about 30-40% of all the projects, is done using Digital Project, combined with the use of Rhino for the initial conceptual design and the use of AutoCAD for producing construction documents. Revit is used for about 20% of the projects. The remaining 10-15% of the work is done using Bentley's BIM solutions by a group that is very comfortable with Bentley's MicroStation platform.

Thus, the firm is essentially agnostic to the kinds of tools that are used on its projects, and has made no attempt to standardize on one set of applications or processes that all its employees are forced to use. Despite the overhead of maintaining all these multiple tools and providing related training and support, the firm finds that being proficient in multiple platforms provides it with more flexibility, more innovativeness, and more opportunities to work on many different kinds of projects and serve a wide variety of clients. The choice of what tools to use for a particular project depend upon various factors such as the style and geometry of the design, the stage it is in, the group it gets assigned to, the kind of contract it is under, the deliverable that is required, the tools that the consultants are using, and so on. This is also often a matter a debate within the firm, as the choice of tool is considered critical to the success of a project. It should be noted that Zaha Hadid does not use any digital tools herself and prefers hand-drawn sketches, but she is closely involved in the iterative design processes, providing inputs and feedback to the designers who are using modeling tools to give digital shape to her concept sketches.

The use of Digital Project, in particular, is critical for many of the non-traditional architectural projects that are the hallmark of Zaha Hadid Architects. It has a very powerful geometry engine with a high level of precision for both surface and solid modeling, which makes it relatively easy to use for creating complex forms. A lot of information can be contained in the model, and the ability to create relationships between the different parts of the model contained in different files is very helpful. The drivers that can be used to control the building geometry make it faster to explore different configurations, even for complex building forms. Overall, it is a very powerful application that combines the functionality of 3 to 4 different applications, including parametric design, documentation, visualization, clash detection, 4D scheduling, and others. It can easily handle large projects and distributed workflows, with multiple team members working on one project often located in different parts of the world. The firm has had great success in using Digital Project in conjunction with Autodesk Vault to manage project workflow and files. Vault is really an MCAD application, but given that Digital Project is based on the MCAD application, CATIA, it is easy to see why these two applications work so well together.
The only downside to Digital Project from the firm's perspective is that it is not suited to the early design stage because of its lack of sketching and conceptual modeling capabilities. The use of Digital Project on a design requires rigor and a clear idea of how it will be organized, and therefore, it is used only after a design has been set in its basic logic.

The firm does not find Digital Project particularly difficult to use, given that it also uses applications such as Maya and Rhino. Also, many people who come to work for the firm are from manufacturing backgrounds and are already familiar with MCAD applications like CATIA. In generally, most people working in Zaha Hadid Architects are very technology savvy, which makes training relatively easy. Vendors are often brought in to teach a basic class, which is then supplemented with in-house training provided on an as-needed basis.

The Galaxy SOHO project in Beijing designed using by Zaha Hadid Architects using Digital Project (Courtesy: Zaha Hadid Architects)

The biggest challenge that the firm faces is in exchanging information between different applications, particularly those used in-house and those used by consultants. The problem is greatly compounded by the diverse number of tools used by the firm and typically by its consultants as well, which means an exponential increase in the number

of application-to-application exchanges. Because there are no established standards for exchanging model information—the IFC was found to be quite ineffective and is not used at all—the firm has had to write custom scripts to facilitate data exchange between different applications. The exchange also depends upon how the application is used, which means that the same script may often not work even for two different groups working in the firm, either at Zaha Hadid's or at the consultant's end—for example, at Arup, which is an engineering firm that Zaha Hadid works frequently with. File format changes in applications, common in many Autodesk applications, also require scripts to be updated. Thus, the firm is constantly working on a large number of scripts for exchanging information to facilitate collaboration. Often, it has to be content with just getting the model geometry from its consultants instead of the complete BIM model, but this at least allows it to do design coordination and clash detection. What it would really like to see in the AEC technology industry is a parametric file standard, so that exchanging information between different applications would be a lot more straightforward—it does not want to be locked down to one platform just for the sake of better integration.

As far as the software vendors are concerned, Zaha Hadid Architects finds all of them very supportive and responsive to their needs, but does acknowledge that this could, in large part, be due to the prestigious nature of the firm. Despite already having a large repertoire of tools, the firm is open to adopting more and is constantly exploring and testing other tools and new technologies and debating on their use. It would like to continue to be nimble and resilient, so that it can take full advantage of technology innovations constantly happening in the building industry.

Analysis and Conclusions

The results of this study clearly indicate that there is no "best" solution that is superior to all the others. All of the six BIM applications that were evaluated have their strengths as well as limitations. While both of these have been discussed in depth in the individual evaluation sections, it is helpful to look at the main points that have emerged from the comparative analysis charts as well as the implementation studies. These are summarized under the main categories that the different evaluation criteria were grouped under in the evaluation tables.

Application Repertoire

Aspects that are well developed in most, if not all, of the applications include the detailed modeling of the building, scheduling and reporting capabilities, quantity-takeoff from the model, the ability to generate drawings from the model and keep them coordinated, and full-fledged capabilities to produce construction documents with keynotes, text, dimensions, sheets with coordinated numbering and title blocks, hatching and other presentation graphics, etc. BIM is now being used "all the way through" on projects, without requiring the project to be moved from the BIM application to a drafting program like AutoCAD for completion.

Most of the applications also have good built-in ability to generate photorealistic renderings. However, the implementation studies have shown that firms are still using dedicated visualization software for creating the final, presentation-quality renderings, primarily because their in-house visualization specialists have mastered the use of software such as 3ds Max and Cinema 4D and are comfortable continuing to work with these applications. Integration between BIM applications and external visualization applications is continuing to improve; for example, ArchiCAD has bidirectional integration with Artlantis, Allplan has bidirectional integration with Cinema 4D, and Revit supports a special FBX format that allows model geometry, lights, and cameras to be exported to 3ds Max. Also, starting with the 2011 release, the Materials library is common across all Autodesk applications.

Support for conceptual design in BIM applications is improving, although none of them still come close to offering the fluidity and ease of use that SketchUp provides. Functionality that is still under-served in most BIM applications includes space planning and programming, so firms interested in these capabilities will have to rely on a third-party application like Trelligence Affinity, which integrates bidirectionally with both Revit and ArchiCAD. Also, with the exception of Digital Project, most of the BIM applications do not fully support the ability to fabricate directly from the BIM model.

Intrinsic Nature and Capabilities

Many of the applications did not do as well in this category in comparison to the other categories. The only aspect in which most applications scored a high rating was customization capability, except for Revit, which still has a limited API and scripting capabilities compared to the other applications. Revit was, however, the clear leader when it comes to ease of use, which is particularly important to firms that are still in the process of transitioning most of their workforce from CAD to BIM. While applications such as Bentley Architecture and Digital Project score high on the complexity factor, the implementation of these applications in firms like Jacobs GBNA and Zaha Hadid Architects shows that once the use of these applications is mastered, they can be used as easily and effectively as the "easier" BIM applications. Other interesting aspects to note are that the form-making capabilities of BIM applications have greatly improved, although firms such as Zaha Hadid Architects rely heavily on

applications such as Maya and Rhino to come up with the initial conceptual models for their unusually shaped building forms. In terms of ease of project setup, this is much more straightforward in the centralized BIM applications than in the distributed ones.

Half of the applications rated poorly on aspects such as the creation of parametric forms and the associative behavior of building elements. But with the other half of the applications doing better on these aspects, the remaining vendors do have precedents that can guide them towards developing these capabilities in their solutions. One aspect, however, that all the solutions failed on is the guarantee of model integrity. Most of the applications do not impose any kind of modeling constraints at all, and even in the case of Revit that does provide some constraints, these are far from sufficient to ensure that an incorrect model is not created. Of course, imposing constraints can be inhibiting to designers, which is why the BIM vendors have preferred to avoid them altogether and let model integrity be checked by external applications such as Solibri Model Checker. This "model checking" is important before passing on the model to downstream applications such as energy analysis, egress, fire safety, circulation analysis, construction scheduling, etc. to ensure that they work properly and give reliable results. It would be great if the BIM vendors could come up with innovative solutions to this problem, similar to how a word processing application includes spell checking and grammar checking, which highlight errors that can either be corrected or ignored by the user.

Issues Specific to Large Firms

What is common to large firms, such as those represented in the LRFT, are large projects and distributed teams, often located in different parts of the world. Prior to BIM, the distributed workflow problem was considerably simpler—different members of the project team simply worked on different sheets. Of course, this had the problems of coordination and inaccuracy that BIM has been engineered to solve, but it was definitely more flexible from a collaboration standpoint. With BIM, the collaboration problem is much more complex as all the project team members have to work on a single model of the building rather than on separate sheets, especially in applications that have a centralized model approach such as Revit, ArchiCAD, and Vectorworks. ArchiCAD has been able to develop a very effective solution to this problem with its new server-based collaboration solution, and it remains to be seen how quickly applications like Revit can catch up. Revit does have its own worksharing capability with a transparent element borrowing capability that has made collaborating on a project a lot easier, but it still lacks the speed, ease of use, and fluidity of ArchiCAD's collaboration solution.

In contrast to the centralized applications, for BIM applications such as Bentley, Digital Project, and Nemetschek's Allplan in which the BIM model and associated information is distributed across multiple files, the collaboration is a little less problematic since different team members can work on different files. Likewise, the distributed applications are better able to support large projects as compared to the centralized applications, since they distribute the model data across multiple files instead of containing it in one file. However, these benefits do come at the expense of more complexity, more involved project setup, and limited object associativity across files. To its credit, Digital Project does not share the last limitation—it is engineered so that the different parts of the model distributed across multiple files still behave as a consolidated whole. It has also developed a smart display technology that allows even very large models to be easily opened, viewed, and edited without any significant slow-down in performance.

Interoperability

Most of the BIM applications are doing quite well on the interoperability front, featuring direct API-level integration with other disciplinary applications and analysis tools. Applications such as Revit Architecture, Bentley Architecture, and Allplan Architecture have the edge here as they are part of a tightly integrated multi-disciplinary suite of applications, which makes multi-disciplinary design within their platforms easier to coordinate. Digital Project also has its own set of add-ons for structural and MEP engineering, while ArchiCAD has an MEP add-on and uses the IFC to interoperate with leading structural applications like Tekla Structures. Vectorworks Architect scores lowest on the interoperability front, featuring no integration with other applications except through the IFC format.

With regard to the IFC, while all of the BIM applications have received IFC certification, the firm implementation studies have shown that it is not working very well for firms in day to day practice and is hardly used. This points to the need for some urgent action to be taken in the AEC industry, either to overhaul the IFC format to make sure it is actually working as intended, or to develop some other standard for interoperability. As the experience at Zaha Hadid Architects shows, way too much effort is spent on developing translators to exchange information from one application to another. This can well be avoided if there was a standard that actually worked. From that perspective, Bentley's new "i-model" concept for collaboration and interoperability is intriguing, and it should be interesting to see how it develops.

From the standpoint of third-party development, Revit clearly leads with an ever-growing ecosystem of plug-in tools developed by other vendors. One only has to visit Autodesk University to be a testament to this—the number of Revit-related tools that are exhibited keeps increasing every year. For example, Revit is the only BIM application so far that integrates with specifications solutions developed by third-party vendors, allowing the time-consuming process of creating project specifications to become much more efficient and accurate by automatically pulling out relevant specifications-related data from the model. ArchiCAD has also done surprisingly well on the third-party development front despite the fact that it is not the market leader—this is likely due to the strength and ease of use of its API. Bentley, in contrast, develops most of its tools itself or brings tools in through acquisitions; there is relatively little third-party tool development activity on its platform.

Implementation and Vendor

From an implementation perspective, most of the BIM applications are relatively straightforward to deploy, and their pricing is quite comparable, except for Vectorworks, which is half the cost of the other applications, and Digital Project, which is almost twice the cost. All the vendors, except for Graphisoft, provide fee-based training. Graphisoft has gone out of its way to provide high-quality learning resources for free to its users and also has good built-in documentation, setting a high standard for other BIM applications to aspire to. Most of the vendors are generous with support requests and make a good effort to support their users. However, Autodesk lags behind a little in this regard, and Nemetschek AG does not seem to have good support beyond Germany where it is headquartered.

As far as the vendors go, Graphisoft again earns highest points for responsiveness, both from large and small firms alike. It has very technologically-savvy leadership that has been able to deliver many innovations in recent releases. Despite trailing significantly in market share in the US compared to Revit, it still has great long-term prospects, given the financial backing of Nemetschek. Revit's leading position in the market is, of course, all but guaranteed

given that it belongs to the 800-pound gorilla in the AEC technology industry, Autodesk. This can be clearly seen from the BIM implementation among the AIA LFRT firms, which is completely dominated by Revit except for Jacobs GBNA and AECOM, which both use Bentley's BIM solutions and Revit equally, and Anshen+Allen, where ArchiCAD still dominates. Bentley's solutions also have good long-term viability, since Bentley is a strong company that is steadily growing in the infrastructure industry as a whole. Also, like Graphisoft, it is led by a management team that is very strong in technology, which is likely to continue to innovate and improve upon its offerings. Digital Project is so specialized that it will always appeal to firms such as Zaha Hadid, and Allplan seems to have secured its future at least in Europe. Vectorworks Architect is the only application whose long-term viability is rated lower than the other applications, but its low cost and ease of use should help to sustain its market among small firms looking to gradually transition to BIM.

Implementing Multiple BIM Platforms

The implementation studies have highlighted several firms such as Jacobs, Morris Architects, and Zaha Hadid Architects that have made a conscious decision to implement more than one BIM application despite the larger overheads of IT management, training, and support. As stated in the Executive Summary, developing expertise in more than one BIM application might, in fact, be prudent for *all* the AIA LFRT firms, given their size and the large and diverse number of projects they handle. Since all of the individual BIM applications that were evaluated have their individual strengths and limitations, with no solution emerging as decidedly superior to the others, implementing more than one solution allows a firm to enjoy the "best of many worlds"—the different strengths and continuing innovations in the different solutions. While standardizing on one BIM application may be convenient and cost-effective, implementing additional applications also gives the firm the benefit of not being locked down to one solution and one vendor, greatly increasing the firm's leverage with all of its vendors.

Future Outlook

The introduction of BIM has been a terrific development for the AEC industry, a step towards a more efficient way of designing and constructing buildings. However, it should not be seen as the be-all and end-all of AEC technology. A lot more remains to be done. Compared to other fields such as EDA (electronic design automation, or CAD for the computer chip industry) where the lower level design tasks have almost entirely been automated, BIM is still a relatively "dumb" technology where the user is forced to model everything in the building. Take the simple example of a space. It has traditionally been represented by architects on paper using a single outline, which to them, not only represents the walls of the space, but also its spatial area and volume, and its floor and ceiling slabs. In contrast, in BIM applications, you have to separately model the walls, the floor slab, the ceiling slab, and then add spaces inside the walls to designate the rooms inside. Why can't all four steps be achieved with a single step? One of the reasons why an application like SketchUp has become so successful is because of the smart inferencing it applies to the task of 3D modeling, which makes the modeling a lot faster and more intuitive. Going forward, we need similar smart inferencing capabilities in our BIM applications to reduce the number of routine modeling tasks required to build a model.

Other computing technologies that can be gainfully applied to BIM applications are rule-based systems that capture design knowledge and rules to automatically design lower-level details, leaving the designer to focus on higher-level design decisions. This is very commonplace in the EDA industry, as mentioned earlier, and there are also some precedents for this in AEC technology. For example, a solution called SITEOPS is available that applies design rules and optimization algorithms to provide optimal solutions for the layout, grading, and drainage of a

site, given a set of parameters including the site plan and building footprint. Another example is the use of rule-based systems by the manufacturers of pre-engineered metal buildings such as Robertson Ceco Corporation to automate their design and engineering tasks.

Thus, BIM is still very much a work in progress. Vendors not only have to work on fixing the current limitations in their applications that have been pointed out in this study, they also need to work on making BIM much smarter and easier to use. The currently available BIM solutions are very important because they form the platform on top of which these future, more intelligent technologies can be built. We need to ensure that the field of BIM is constantly moving forward and does not stagnate as CAD did for so many years. Technological developments are critical to advancing the state of the art in any industry, and AEC firms should continue to demand better and smarter technology solutions from their vendors.

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Lachmi completed her Ph.D. in Architecture at UC Berkeley, specializing in the application of computing technology to the building industry. Her thesis was focused on developing a computational representation of a building that could be analyzed and evaluated, in line with present-day BIM concepts. Her earlier credentials include a professional B.Arch. (Honors) degree from the Indian Institute of Technology, Kharagpur, India, and an M.Phil. in Architecture from the University of Cambridge, England. She worked on several design projects as a practicing architect in India and has taught CAD and 3D modeling for several years at UC Berkeley. In addition to writing in industry publications for several years, she has authored books on CAD and modeling. She continues to stay closely involved with the research community, recently serving on the editorial board of the journal, Automation in Construction. She can be reached at lachmi@aecbytes.com.