3D Modeling for the Architectural Engineering and Construction Industry

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ABSTRACT

Residential design and construction relies heavily on construction documentation to convey not only form and function, but also to aid in the estimation and marketing of the structure. If done with traditional methods, residential design and construction requires many people and hours to gather the data in useful forms. The traditional documents that are necessary for the construction processes are the estimate, bill of material and construction documents or working drawings. Furthermore, technology is providing marketing alternatives such as three-dimensional models for visualization, simulation and spatial analysis.

In today's extremely competitive construction market, it is logical to identify ways to combine tasks in order to save time and money. The advent of Computer Aided Design in the construction process has saved an abundance of time and energy, but these tools are not being utilized to their full potential. Some designers and architects are simply trading in their board and T-square for a mouse and a monitor, but the idea of a computer is to advance current practices, not just be an alternative method. The computer, if utilized correctly, can create not only the traditional two-dimensional data, but also three-dimensional information that can provide construction documentation and marketing requirements.

The availability of multiple AEC products can make it very hard for the user to select the correct application for their company. This leads us to research in the comparison of the products available. In this paper, we have chosen to compare and contrast "geometric modelers" versus "parametric modelers" to show the benefits and drawbacks of each.

Keywords: Object-Oriented Modeling, Parametric Modeling, Imaging, AEC, AEC software, and Visualization

1.0 INTRODUCTION

Modeling has proven to be extremely beneficial to the Manufacturing industry as displayed by the automotive industry modeling entire cars, or plastic companies solid modeling parts; then generating a rapid prototype to verify interaction and tolerances with other parts on the proposed item. According to Ethier and Ethier [1], modeling can provide us with a wide range of benefits, and deciding on which modeling package to use for the AEC industry can be challenging. Also, deciding on which AEC modeling package to teach students can be even more challenging. The benefits to the students must be researched and evaluated to give students the best opportunity for future employment.

Architects and residential designers are extremely slow to reorganize and accept technology and, therefore, change their working environment (Christin [2]). This fact has caused most to miss the opportunity that exists in computer design. This intelligent model would be an interlining of data, materials, and documents through the use of parametric technology. From this intelligent model, a single designer would be able to generate the plans, sections, details, specifications, estimate and bill of materials to create a realistic simulation for marketing. Within this new paradigm, the renaissance person would be eliminating unnecessary steps, errors and overhead previously expensed to create marketing and construction documents.

3D concepts aren't something to put off until a later day; they are used in every aspect of modern computer-aided design work, states Mathews. [3] It is from this statement that we will look at and define the modeling abilities and procedures within several software packages, and look at the different packages with a focus on the AEC industry.

2.0 AUTOCAD 2000 IN AEC

AutoCAD has been identified as one of the leading software packages currently used by industry and educational facilities. Standards from the software package have been undeniably adopted by other software packages, such as the *.dwg* or *.dxf* formats. It is for these reasons and more that most educational institutions have introduced it to their students. The AEC industry has followed suite in the utilization of AutoCAD for the generation of working drawings.

The initial start-up of the package is like most: set your drawing limits, identify the units, set the accuracy of the units, and identify a size for the grid and snap. These elements which where crucial in the start-up of 2D drawings are not as necessary in 3D modeling. Items that are of importance are location of the object in relationship to the world UCS, location of the origin for blocks, spatial visualization, and manipulation of the UCS for cognitive visualization. The user must be aware that this package has the ability to create more than one type of a 3D model.

AutoCAD allows the user three geometric forms of modeling: wireframe, surface, and solid modeling. Matthews [3] identifies the wireframe model is a skeletal description of a 3D object, and due to the skeletal simplicity, it's fast and economical within the CAD database. Wireframing have no surfaces associated them; just lines and arcs which represent edges or limits and vertices of the object. This form of modeling is a nice transition from the 2D drawing mode into an introduction

of 3D visualization. Wireframe models unfortunately do not allow additional information, such as area or volume, to be associated or attached to them and are therefore primarily utilized for visualization. Wireframe allows the user to visualize the object in its entirety, front, sides, top, bottom and back all at once; but does not allow the user to see the object as in real life.

The surface model is the next area which has wireframe aspects, but with a coat or skin over the frame. Surfacing uses the wireframe geometry and complex algebraic equations to define an area between lines or edges of the model which then produces a surface covering the object. The area defined is a general polygon mesh that is planer.

The last type is the solid model. The space that forms the object is enclosed by surfaces, which forms a closed volume. Users can create solid models from standard primitives, composites, extruded, and/ or revolved solids. Users usually find solid modeling easiest to use and understand.

What information constitutes a complete model?

1. Form
    a. Shape & Size
2. Attributes
    a. Materials & Physical Properties
3. Relationship/Assembly
    a. How parts are related
    b. What moves with what
4. Behavior
    a. Doors opening and closing
    b. Structural Members under load

All of these items are components of a 3D model according to Fallon [4]. Some aspects of the 3D model are easier to achieve than others- given the software used. How does one achieve a true model or something close to a 3D model with simple software packages like AutoCAD?

Object Linking and Embedding (OLE) is one way that AutoCAD users can experience more of the components of a parametric modeling software package. The idea of copying and pasting data between different files in the same software package is fairly common knowledge, but copying and pasting from a word processor or spreadsheet into a CAD program is something CAD users will have to get used to. Given a drawing with a bill of materials that is created in Microsoft Excel, the user can copy the data from excel and paste it into AutoCAD to print out. The pasting of the excel spreadsheet into the CAD file forms a link between the two software packages. If the data in the spreadsheet is modified, the information in the CAD drawing can be update manually or automatically depending on how the users specified the linking process. The unfortunate part is the user must create the bill of materials manually before he/she can insert it into the CAD drawing. The ability of OLE linking allows the user to experience what a true 3D modeling or parametric software does automatically.

The AEC Institute, an American Institute for AutoCAD drawing standards, does not lend itself to the use of these modeling types and OLE linking efficiently without help of supplemental plug-ins or software modifications. It is for this reason that AutoDesk and other software companies have relentlessly pursued 3D Modeling for the AEC industry. Currently, AutoDesk has developed a couple of products geared directly toward the AEC industry. Softdesk and Architectural Desktop is just a couple of the products available. Other products from other software companies include Ketiv, Arch T and Eaglepoint to name a few.

3.0 MODELING WITH ARCHITECTURAL DESKTOP

Architectural Desktop is one software specifically designed for the AEC industry. The integration of the AutoCAD 2000 tools and architectural objects-oriented features allows improved productivity for the AEC user. Having object-oriented features allows the user to utilize features from the conceptual phase into the design phase and finishing up with the final construction documentation. Identifying the object-oriented features allow for comprehensive and accurate documentation.

The first of the features is surface modeled walls. The walls are an extrusion of the multi-line command. Depending on how the wall is shown is dependent on how it is viewed. In the 2D plan view, walls are viewed as parallel lines or would be seen as a traditional set of floor plans that a carpenter uses. The view of the walls in the 3D orientation is shown as parallel surfaces or as walls in a real world scenario. The z-height is predefined before insertion of the wall component. After the height has been determined, the insertion of the wall is similar to the insertion of the multi-line or individual line commands in AutoCAD 2000. The comparison of commands between the two packages makes the transition relatively easy. Walls can also be customized with properties that can identify specific wall types by sight or verbal description. Association of wall types with verbal identification and visual reassurance can only benefit those individuals utilizing the documents during and after the construction documentation process. Walls are not the only benefit to this software package.

Doors, windows, and openings have a parent/ child relationship with the wall object. The software does a Boolean operation on the surfaced wall object and inserts a door or window object into the opening. The relationship is identified when users select a door to insert into a wall; the door is constrained within the wall object. Sizes of doors and windows are easily adjusted in the menu by creating a door and window database with the most common sizes used within the model. This database of objects may be used individually within the specific project or imported into other documents to be utilized within that project. The ability to make use of one database over and over will only enhance productivity. The initial costs are sometimes overlooked when companies make the switch from traditional 2D drawing to 3D modeling. Those initial costs include an individual taking the time to create all the windows, doors and openings within a database to make us of within upcoming projects. In some cases, this process can take days or even weeks depending upon how many sizes, styles and brands of windows or doors the firm uses in projects.

Roof systems, stairs and handrails are more features included in the software package. The generation of a roof system (in the 2D form) can be challenging at times to visualize. The more

complex roof systems can even take multiple individuals input to figure out. Roofs are not the only troublesome component within construction documentation. Stairs can be just as bothersome when the project has a specified opening size and the set of stairs will not work with the given specifications. Visually, students and even professions have a difficult time understanding how the stairs are inserted into an opening. Architectural Desktop has greatly improved the process of roof systems and stair insertion. For the roof system, it is a mater of defining the original slope of the roof, then identifying the corner points of the building that the roof system will rest upon. This is an over simplification of the process, but it does provide individuals an easy way to insert a roof system to get a quick visual reference for the structure. It will take the user some drive time on the system to understand the intricacies of roof systems in Architectural Desktop.

Stairs might seem just as easy, but the user must understand the process behind what the software is doing. Total rise; tread width, riser height, and minimum headroom height are concepts that must be understood before the individual proceeds into stair insertion. Otherwise, the individual is just placing several lines that represent steps into the project just as it might have been done in the 2D traditional sense. Architectural Desktop has greatly improved productivity and efficiency during the construction documentation process for the AEC industry; but without understanding of the concepts and procedures of the construction process, individuals might as well be drawing in a traditional 2D method.

The benefits for companies and students to utilize 3D modeling in the AEC industry can be greatly beneficial. Fallon [4] states that the benefits of intelligent modeling approach to the AEC industry are increased productivity, reduced cycle time, better work flow amongst group members, and life cycle applications. These are important concepts and valuable concepts to people that are concerned with project management; but unless the user has a firm grasp on the entire construction process, only a few of these concepts will be utilized to there full potential. Other modeling software packages make it crucial for the user to understand the entire construction, 3D visualization, and database management processes before they begin to draw line one. It is these packages that we will look at next.

There are problems associated with Architectural Desktop, not just benefits. The integration of the software package with other products is not as efficient or easy as lead to believe. The biggest problem is lack of experience accomplishing task. The user has a good understanding how to get things done traditionally or with 2D programs, but when the software is supposed to generate items automatically and the user does not know how to accomplish the generation, it causes extreme techno-stress. Due to high expectations of existing AutoCAD users, the first two versions of Architectural Desktop did not function as promised and disappointed all users. The June 2001 issue of Cadence has an article that claims Architectural Desktop (ADT) 3.0 corrects deficiencies from earlier versions. The authors' will be reviewing and determining ADT 3.0 benefits and deficiencies.

4.0 MODELING WITH PARAMETRIC SOFTWARE

The next generation of software technology for the AEC industry is based upon databases and intelligent geometry, commonly referred to as parametrics. The basis behind a parametric modeler is the use the entire structure as a 3D database to build digital information. Some of the AEC parametric packages include, but are not limited to Argos BDS, Vertex BD, CadSoft, and Softplan.

"Parametric Modelers have been around for quite a while. The majority of these types of modelers are specifically designed for the engineering industry. These programs include, but are not limited to Pro-Engineer, Iron CAD, Catiev, and Solid Edge [Bozell [5]."

"While these programs are very productive in the engineering industry, they are not at all suited to the migration to the AEC industry [Risch [6]." Because of this, a few companies have developed parametric software specifically to fit the needs of the AEC industry.

In these programs, information is organized into a traditional construction sequence, so that the migration from a "geometric" modeler to a parametric modeler can be as painless as possible.

Through the use of forms, macros, databases, and architectural data created in a parametric intelligent model, you can extrapolate the data that is needed to put the model into production (Risch [5]). This changes the old CAD paradigm of drawing lines as representations of material. To create an accurate model, the correct material needs to be selected and used in the virtual construction process.

4.1 Argos BDS

Argos BDS is a residential specific AEC parametric software package. Like the other parametric software packages, it stores all the project data into a database. Building design and project information is organized into a project specific database that includes all the files relating to that project and stores it in a single project directory on the hard disk. This allows for easy access to all information such as materials, customers, and project parameters. This also allows for universal project changes. Since all the information is tied together, one change will universally change the project. For example, if you would change the wall height from 8 feet to 9 feet, all information and graphics that are tied to that height are updated to reflect the change both in the 2D and in the 3D.

When a new building is designed, the user first creates a project file by filling out a project information form. The data within the form are all users defined and can be customized to suit each individual company. The project form can also include pre-defined aspects of the project such as building type, framing materials and methods and finishes.

4.1.1 Wall Design

The first step in designing a home is the layout of the building. Typically in a "geometric" program, the user would draw a line or a 3d rectangle to represent the wall. This is fine if all you want is graphics, but the ultimate goal is to have everything integrated so that everything is stored in one place, and there is no duplicate data in the project. "It's our position that not having to duplicate information and having software that can draw on the resources of other software is really critical, good management." (Smith [7])

This leads to the concept of drawing specific types of walls in the 3D model or database of information. A user will first go into the walls database and select the appropriate type of wall that they are going to use to build the wall. This wall database will contain all of the information and material needed to build that wall. For example, if you choose an "Exterior 2x4 wall with brick" from the database, the wall that you place down, will not only have the 2D and 3D lines necessary to represent the walls, but will also contain the material needed to build the wall such as studs, square foot of drywall, square foot of brick, and how much insulation is necessary for that wall. By associated these materials with the wall, you are essentially building the entire structure from start to finish in the computer. This is what will give the user an accurate material list that can be utilized in the entire building process.

4.1.2 Doors and Windows

Every builder will use a different type of window or door manufacture. For this same reason, every manufacture will have a slightly different rough opening size for their doors and windows.

Just like with the walls, a parametric modeler will ask the user to select the type of door or window that they want to place in their wall. Depending on the selection, the materials and rough opening will be adjusted. When the user has selected the appropriate door or window, they simply have to place it in the wall they want. The parametric software will then cut out materials and graphical information from the model and substitute in the material and graphics for the door or window.

Again, by having a database behind the graphics, users are able to have an accurate 2D plan, 3D model and material count for the estimation of the building.

4.1.3 Floors and Ceilings

Floors and ceilings contain the information such as floor sheathing, ceiling drywall, floor joists, rim joists, ceiling joists and blocking. The user will select what material that they wish to use in their construction as well as how they wish the software to build the building. The parametric software will then take the information selected from the database and build a 2D plan and 3D model that will reflect how the building will be built.

4.1.4 Macros

AEC documents have a lot of information in them of what is contained in the building. For example, kitchen cabinets, sinks, toilets, closet shelving, stair cases, HVAC, plumbing, and lighting to name a few.

In keeping in line with the parametric modeler, the user will select from a database what they would like to add into their AEC model. By selecting from a database, they are able to attach a 2D and 3D model of the object as well as have specific information attached to that macro such as price, labor, manufacture, product number, or any other information that they want. Once this information is placed into the model, the information can be extracted into a materials list that can be passed on for estimation, purchasing, or project management. "What we're tying to do is bring all parties in a construction project together." (Unger [7])

4.1.5 Materials Management

Much of the power and flexibility of a parametric modeler is a direct result of the integration of the graphical data with the materials database. This enables the user to attach any number of material items, components, or characteristics directly to its graphical symbol. Therefore, once a plan has been completed with all the elements, the system then automatically creates a model of the design. The parametric modeler then has all the criteria defined to automatically generate a complete bill of materials and cost estimate for the project. The system also allows the user to include labor and waste factors to further refine the cost estimate.

4.1.6 Integration with other Application

Why would anyone spend the extra time needed to build a parametric model? Well, the answer lies in data management. With the capability of extracting a materials list from the 3D parametric models, you have the ability to eliminate the need for estimation on a project created into a parametric system.

The information extracted has the ability to integrate into other software programs used in the AEC industry today. These software programs include Timberline, Primavera, Sure Sell, and many other AEC packages.

By combining tasks, companies will have the ability to same time and money on projects. They will also have the information stored in one place. The graphical information from the model has the ability to integrate into the aforementioned packages such as AutoCAD and 3D Studio MAX / VIZ.

4.1.7 3-Dimensional Models

Because all components within a parametric modeler are created as 3D elements, it allows the user to quickly view and compare various design choices interactively. The building model can also be rotated to generate additional views and perspectives.

As discussed earlier, all elements will have the information already attached. The designer, therefore, can view alternatives and instantly evaluate their impacts on both the final design and budget. The result is a more cost efficient design and better materials utilization.

The advantage of having the 3D information available allows the creator to check for errors that might occur in the drawing process.

4.1.8 Automatic Options System

Increasingly today, builders must respond to the growing requests for customization from prospective buyers. The ability to incorporate pre-defined options and design changes into a particular building plan can have a tremendous impact on project completion time, construction costs, and profitability.

Argos BDS has developed an Automatic Options System into their product. To data, it is the only one of its kind. This system allows companies to define a base design model and attach pre-defined options selections to it. These options are completely user defined and can be in any form the user chooses. When an order comes in, the user merely selects the desired options from the options list. Argos then combines those specific options together, revises all the appropriate drawings and updates the pricing and bill of materials.

With the Automatic Options System's flexibility, the user can easily setup the building options to meet whatever needs may develop. The system can also be used as an effective sales and marketing tool. Sales representatives or dealers can select various design options with a customer and instantly show them the final design and the costs associated with their selections.

4.2 Revit

The latest development in AEC software is Revit from Revit Technologies, Inc. Revit is a "true" parametric program unlike a lot of the other AEC software on the market. The data entered into the system is completely bi-associative, which means that all the drawing files are linked together. You have the ability to go to the window schedule, adjust the sizes of the windows, and it will update the 2D floor plans, 3D model, elevations, sections, details and any other drawing that has the changed window in it. This can save the user a tremendous amount of time especially if the change comes after the documentation has been completed. Typically in AEC parametric software such as Argos, you only have the ability to change items in the 2D plan and have it change the 3D. All other drawing files must be changed by hand.

Revit is based upon the popular mechanical engineering parametric software package Pro-Engineer from Parametric Technologies, Inc (PTC). The original creators of Pro-Engineer sold their company and began Revit Technologies to address the needs of the AEC industry. Revit's first priority was to make the user interface user friendly and easy to use. Their concept was to make the interface as familiar as possible by designing the menus to look like Microsoft Outlook. This will immediately give the user the sense of familiarity and help them work through the functionality of the program. (Figure 1.1)

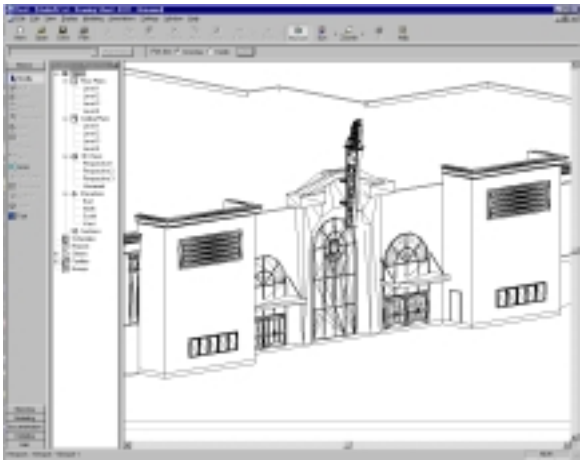

Figure 1.1

Revit is based upon family groups and databases just like Argos is based upon Macros and databases. Family groups are all of the intelligent elements that you put into your drawings that will be collected in the Bill of Materials (BOMs). The standard family group that is installed out of the box is very extensive, but you also have the ability to download extension family groups from the Revit web site or from the user groups for free. In addition to downloading family groups, the experienced user can create their own custom family groups.

Revit used the very popular RS Means standards for collecting the BOM or estimate of the structure. The software, with a click of a button, will read the drawing files and all of the family groups and create an estimate based upon these RS Means standards. There are still quite a few shortcomings with this type of estimate, but Revit is only in its third version and Revit has stated that they are addressing this problem and will have a more accurate estimation package in their future products.

Revit Technology, Inc. has one of the best academic programs to date. Any academic institution can utilize their software at no cost. All that is needed is a short proposal of where the software will be used and an update at the end of the semester on the use of the software as well as some example student work. Furthermore, Revit will allow students enrolled in the classes to have the software on their personal home computers at no cost. From an academic standpoint, it is very encouraging to see a company that has the vision to work with academic institutions to help in the development and distribution of their product and knowledge.

Revit, while still in its beginning stages, has extreme potential. The program is organized in a very functional form. Instead of slowing down or hindering the design and documenting process it will actually enhance and make the designing process easier and productive.

5.0 PRACTICAL ISSUES

Today's AEC professional worries about several items during the course of a day or the life cycle of a given project, but when it comes right down to it- they worry about production and money. Some items that should concern professionals when deciding whether or not to plunge into 3D modeling are:

1. Design costs and time
2. Software learning curve
3. Software costs
4. Ability of the software to handle complex geometry
5. Performance of the software- bugs
6. Level of detail needed and what the software will deliver
7. Partition the model among multiple users
8. Integrate model from multiple sources
9. Tools for model review and web publishing
10. Speed and working drawing extraction
11. Maintenance

The overall goal is to keep production levels the same while the transition of the new software takes place. This is where most of the problems occur because the designers are concerned with production and, most of the time he/she reverts to the software they are most comfortable utilizing to accomplish task quickly and efficiently.

6.0 CONCLUSIONS

In today's extremely competitive AEC market and industry, it is logical for industry professionals to identify ways to combine tasks, save time and furthermore, save money. The advent of Computer Aided Design (CAD) in the construction process has saved an abundance of time and energy, but these tools are not being utilized to their full potential. It is unfortunate that most AEC professionals are from the old school and are unwilling to utilize the benefits of 3D modeling. It may be due to their lack of exposure with the software and the benefits using a 3D modeling software package. There has been a noticeable increase in utilization of 3D modeling in the Architectural and Construction areas, but it is a drop in the bucket compared to Engineering and Manufacturing professions.

In this paper, we have reviewed a portion of the AEC software packages available. Each of these software packages possess' their own benefits and limitations. By evaluating your company's specific needs, you will be able to better determine the software package that will make your company efficiently productive.

The fact that there is multiple 3D modeling software products for every type of industry identifies several very important facts before, during and after purchase of the package. First, it should be the foundation knowledge emphasized in the education. The type of software package being utilized should not be a factor, but just a benefit. Second, research is the key to a successful and productive purchase of the software. You really cannot put a time limit on the initial research to identify the best possible product for your company. The last factor is training. Strongly emphasis that your employee's and/ or students take the time to run through the tutorials, or encourage enrolling in a short course dealing that specifically deals and trains on the software purchased. It will save you time, headaches and stress later on if you understand the software before you engage in production.

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