Component-Based, Three-Dimensional “Working Drawings”

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It is now possible to communicate technical information about a building utilizing accurate three-dimensional computer modeling of component assemblies of an entire building for the production of an alternative set of “working drawings.” Most assembly illustrations and final appearance can be presented as output from the computer model. The use of these three-dimensional images in the practice of architecture may improve communication between the members of the building design team and, therefore, may improve the overall design integration of the various systems in a building.

Additionally, this type of component model construction for the production of technical drawings offers a unique bridge over the gap between the practice of architecture and the teaching of architecture. Rather than teaching students how to “do working drawings,” something all practitioners wish the academic institutions did, students would develop the ability to design, integrate, and construct complex three-dimensional assemblies and present them in a variety of ways using the standard sections, layers, view, etc. inherent in any reasonable three-dimensional computer-based modeling system.

Background

Prior to the main discussion it is necessary to define the focus of this effort in order to be clear about the relationship between computer-based representation and design.

“It has often been suggested that although it is clearly demonstrated that computers can solve well-defined problems in the ways that we have described, they cannot display anything corresponding to the original creative thought which we take to be characteristic of a good designer.”

[Mitchell, 1977]

This early statement by Mitchell accurately describes the continued difficulty computer-based representations have in expressing the poetic dimension of architecture and perhaps explains why the machine has been restricted in its use to perform the “well-defined problems” in the practice of architecture, such as numerical analysis and drawing/modeling/rendering. Given this apparent difference between poetic expression and technical description, it is asserted that in the current practice of architecture, there is a point at which a leap in the process occurs from designing to describing. While it is assumed that the creative process continues throughout the more technical process of describing the assembly of a building, it occurs with a much greater awareness of actual materials and assemblies, rather than the broad, poetic brush stroke representing early design gestures.

It is within this context of describing the technical aspects of design that this paper concentrates its efforts. To develop a foundation on which to suggest an alternative method for describing the technical integration of building components, both the use of computer technology and the use of working drawings in the current practice of architecture are discussed.

Technology and the Production of Architecture

“The division of labour between those who design and those who make has now become a keystone of our technological society. ... (It is) ironic that the very dependence on professional designers is largely based on the need to solve the problems created by the use of advanced technology.”

[Lawson, 1980]

The rapid development of technology and the resulting new fields that emerge from this explication...
of knowledge have fragmented the field of architecture, and have made the production of building design a task that involves many individuals, best characterized as specialists. The ever increasing complexity in technical support systems, the addition of many more individuals to the building effort and the continual increase in the number of performance requirements and codes has made the process of design and construction far too complicated for one person to manage [Alexander 1964].

Initially, the introduction of the computer to the field of architecture was thought to be a technological solution that would be able to deal with the ever expanding technology base in the field. However, when one reviews the current state of integrating CAD into traditional practices, further fragmentation can be seen within the practice of architecture itself. Firms with head designers and separate production staff utilizing computers find that the development of the documents describing the building is done by CAD experts that are not necessarily involved with the design [Franklin 1993]. This “hand-off” [Franklin 1993] of responsibility has had a profound impact on the profession. The very computer that was introduced to improve design by organizing and simplifying the architect’s relationship to the rising tide of technology has merely served to divide it further into those who design and those who operate the machine.

The division of efforts in the production of a building will eventually change as more architects graduate with CAD experience. However, the relative ease with which a computer draws and accurately reproduces information calls into question the impact the technology has had, and will continue to have, on the production of architecture.

“We need to counteract the pressures insisting that the quality-control mechanisms useful for exact replications and industrial plant assembly lines be instituted for one-of-a-kind projects. Otherwise we may all become CAD victims by reason of living with a cookie cutter built environment replicated endlessly by some giant database.”

[Franklin 1993]

Design quality must always be seen as more important than the efficiency afforded by technological advances. Hence the technology within the computer should not be seen as a way to make the design process faster and more efficient, but rather as a way to make design better.

2-D Representation for 3-D Assemblies

“The disadvantage of designing by drawing is that problems which are not visually apparent tend not to come to the designer’s attention.”

[Lawson, 1980]

If the ultimate goal of a building design endeavor is the physical construction of the building in three dimensions, why then, is the specification of design intent vested in multiple, two-dimensional abstractions, or drawings? It is clear that drawings allow the designer to concentrate on specific design concerns in isolation, utilizing multiple representations, and dimensional reduction, to focus design exploration. Additionally, certain drawings such as plans and sections, are irreplaceable as design tools, offering views of the building that go beyond the simple description of construction assemblies [Frascari 1992]. Given the distinct difference between designing and describing as defined earlier, there comes a point at which the description of a building’s assembly is transferred to the contractors for the ultimate construction of the project. This description of the design is what we define as the contract documents, or “working drawings”.

Working drawings are dimensionally reduced, abstract representations prepared by a designer in order to accurately describe the assembly of a building to those individuals that will build it. They are necessary instruments in the current cultural climate in which we practice architecture, since the designer is no longer intimately involved in the construction process of the project. These drawings typically represent the building and the assemblies and are divided into sections according to the type of information or sub-system of the building being presented. The onus is on the architects, engineers and contractors to anticipate conflicts between systems and to design the complex interrelationships between them, utilizing the drawings as the means for communication.

The major criticisms in utilizing the working drawings stem from the very methods they use to communicate information, namely separate, abstract views (floor plans, sections etc.), multiple drawings describing the integrative relationship between the
sub-systems of a building (mechanical, electrical, HVAC plans etc.) and the incomplete presentation of information that the contractor must "fill-in" during the actual construction.

"Often minor standardized features of construction, for the sake of economy in preparing drawings, have been entirely omitted... one would seldom see on a floor plan the actual layout of studs used in wood frame construction or the nails used to fasten them together, yet it is taken for granted that standard 16" spacing of studs will be used to build the wall, and sufficient nails will be used to fasten them together."

Muller [1981]

The ultimate irony of using working drawings for describing a building is the development of yet another specialization in the practice of architecture; the working drawing print checker. Independent methods exist that utilize graphic techniques for checking and coordinating architectural and engineering drawings for the detection and correction of errors, omissions, and duplications [Duggar 1984]. The method introduces still another complicated, specific language of symbols, abbreviations and colors to review a set of contract documents that is already laden with its own unique symbols, abstractions, and abbreviations.

Three-Dimensional Drawings

The use of three-dimensional drawings for design and construction has a long history that spans from the Renaissance to the present. Brunelleschi's use of perspective drawings [Eitinger 77] and Palladio's later use of the pictorial device of projecting a 3-D object frontally onto a 2-D surface represent critical departures in building design and representation.

The current use of three-dimensional drawings has, however, been largely restricted to design visualization during the process of making a building. It is somewhat rare in a current set of contract documents to see three-dimensional drawings routinely integrated. There remains an allegiance to the traditional projected forms of representation of plans, sections, and elevations, and typically, the use of three-dimensional drawings merely further explains an assembly that is already depicted in a series of other drawings. An example of this type of supplemental drawing includes the integration of annotated and dimensioned perspective views into a traditional set of working drawings. The addition of these images can reduce much of the interpretive process involved in constructing a building from a series of two-dimensional drawings (Figure 1) [Vance 93].

![Figure 1: Introducing perspective views into working drawings](Vance 93)]

Component-Based Working Drawings

It is assumed that the paper-based medium for conveying descriptive information about building assemblies will continue to be the main method of communication between architects and contractors for some time to come. Within this traditional practice, an alternative is proposed that will alter the way we think about transferring the technical description of a building to those responsible for its assembly. In an attempt to use the computer in a way that challenges the traditional two-dimensional drawing techniques, a method is proposed that eliminates much of the abstraction, reduces the possibility for errors and undetected interferences while improving the interpretive process of reading the documents. The method suggested relies on the accurate, three-dimensional modeling of a building at the rudimentary component level [Harfmann 89,90,92,93], and utilizes the model for the development of Three-Dimensional, Component-Based, Working Drawings.

In this method, the entire building, including the mechanical, electrical, plumbing systems, etc. would be entirely designed and integrated into the 3-D computer model utilizing individual component-level representation.

The sample of drawings that is presented are taken from a simple 2-story wood frame addition, modeled

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as assemblies of the individual building elements that will be used to construct the project. Since this model represents an actual project with tight budget constraints, specific attention was paid to accuracy and the actual sizes of elements in order to explore the options with respect to material optimization. To illustrate the use of these drawings and their potential impact on the production of architecture, only a few “typical” types of images are presented. From these images it is possible to understand the concept of Component-Based, Three-Dimensional Working Drawings and develop a critical position with respect to their usefulness in practice.

As an alternative organization to the traditional site plan, first floor plan, section, etc., the 3-D component-based drawings are organized and presented according to construction sequence and trade. This method isolates the important information for the sub-contractors and eliminates the information of the other trades and the resultant source of confusion from the additional information. For this particular project, the drawings produced are in the following order; Portions of the drawings in bold print are included for discussion.

Foundation/Site
  Footing, Walls and Piers
  Contours
  Framing
    First floor frame and sub-flooring
    Wall framing and sheathing
    Second floor framing and sub-flooring
    Roof framing and decking
  Exterior Envelope
    Roofing
    Windows and doors
    Siding
  Systems
    Mechanical and duct work
    Electrical
    Plumbing supply and waste
  Interiors
    Insulation
    Drywall
    Trim
    Cabinetry

It should be noted that the drawings produced and their organization should reflect those thought to be necessary for the construction of a specific project. Each project should be seen as an individual, unique effort, and therefore, each set of drawings must be customized to satisfy the needs of the contractor(s).
Framing (First Floor)

Figure 3: The image presented for the framing of the first floor includes dimensions that represent the major features of the floor framing. For convenience, the 3/4" plywood sub-flooring is not shown in order to expose the floor assembly. The drawing indicates where joists are doubled and the location of bridging etc. It is also important to note that although these elements are shown as isolated members, they were taken from the overall model where their relationship to other elements and systems was considered. This is apparent by the specified framing and location of the main supply duct and crawl space access hole. The foundation is included in the image for reference.
Figure 4: The wall framing drawing includes the foundation and floor deck for reference purposes again. Notice that the layout of the plywood sub-flooring has been included in this drawing. With consultation from the contractor, the wall slabs were constructed in two sections and are so noted on the drawing. This results in the addition of at least one stud but will simplify the construction process with regard to the step in the floor. Another major difference is seen in the dimensioning of the stud wall and window. Instead of locating the opening by the centerline, it is possible to indicate the actual distance from the end of the wall to the rough opening for the window. This eliminates the possibility of error in measuring on the site and reduces the interpretative process of the carpenter. It is also worth noting that it is possible to develop from this type of drawing, a detailed list of lumber etc. that includes every stud, joint, and piece of blocking.
Component Modeling for Teaching Construction Technology

The accurate modeling of three-dimensional construction assemblies offers a unique bridge over the gap between academia and practice. Rather than teaching students the techniques and skills of two-dimensional working drawings, they can begin to solve problems in a highly three-dimensional environment. While it is recognized that this is not as effective as the actual "hands-on" construction practice, it does offer a necessary three-dimensional understanding of their work. Given the powerful images that accurate 3-dimensional modeling of buildings can offer, the models and modeling process can be used for a variety of purposes in the teaching of construction technology:

Construction Sequence

Utilizing the layers in the modeling program as a means to organize information, an entire building can be sequentially assembled, illustrating to the students the importance of construction sequence to overall design (Figure 6). While not as good as actually seeing a real building go up, this model offers the ability to accelerate or stop the process for more detailed investigations. For example, it is quite simple to "zoom-in" on a specific portion of the model to discuss the sequence of laying out a stud wall while considering interior and exterior finishes.

Systems Integration

Once again, a typical use of layers can produce images that combine components, illustrating the complex interrelationships between building systems. It is possible for students to explore different types of systems and to see the three-dimensional, spatial integration of the elements in their proposal.

Construction Details

The detailed component model yields the ability for students to explore the details of connection by developing a three-dimensional model of the assembly. This is a rather inexpensive way to visualize the elements and their connection without bearing the expense of actually building the assembly. The digital model also supports multiple views and can be easily manipulated to investigate other assembly possibilities (Figure 7).
Material Sensitivity

Component modeling, at this point in time, is a rather laborious process that requires much thought for the development of the model. The individual creation of each of the components, however, yields a certain respect for the actual manipulation and construction of a building. Perhaps students would be less likely to overstate the poetic possibilities of their design proposals, if they were forced to consider the implications with respect to construction.

Communication

The component model can also be utilized to develop the relationship between the three-dimensional assembly and traditional two-dimensional working drawings. It is quite simple to “cut” a section of the model yielding a 2-dimensional image of the elements that have been severed. When projected with the model behind and studied together with the 3-D image, students can improve their ability to draw two-dimensionally while seeing three-dimensionally. This can greatly enhance the student’s ability to perform in the current practice environment.

Conclusion

The paper has presented an alternative method for the communication of technical information about the actual material assembly of a building design. It recognizes the difference between the creative act and the necessity of traditional plans and sketches in earlier stages of design, but points out deficiencies in the current methods used in the later stages of the process. The method illustrated employs the use of accurate component modeling of an entire building from which three-dimensional images are cut, then annotated/dimensioned and developed as an alternative set of working drawings.

Drawbacks and Disadvantages

The major drawback at this point, is the time it takes to develop the model. Since the project was modeled using Form-Z, a traditional, general modeling package, the creation and manipulation of building elements is a long and arduous task. Changes are difficult since components need to be individually manipulated, resulting in computer-aided remodeling. Additionally, potential interferences between components had to be detected by the user.
Development of the three-dimensional drawings from the component model has not, to date, proven to be faster than developing a conventional set of drawings. It is also difficult to work with conventional wire frame images with the number of small components in the model. At times, the screen appears to be a large mass of intersecting lines making it nearly impossible to discern which line belongs to which component. Furthermore, with the large number of elements created, working in hidden line is impossible.

Another major drawback, or even contradiction, with the use of three-dimensional working drawings is that the images produced are still two-dimensional and therefore, inherit all the difficulties of dimensional ambiguity with two dimensional representations of three-dimensional objects. This is probably most evident in the dimensioning of the images. The vertical dimensions can be easily confused with horizontal dimensions (a problem that does not exist in a straight elevation view). Furthermore, the view chosen directly impacts the clarity of the information presented. Many trial views were cut from the model to determine the projection that was most clearly dimensioned and annotated. The drawing can very easily become cluttered as other elements are added, and the most simple way to avoid this complication is to generate another view. This may result in many more drawings to describe a project than the traditional plan, section, and elevation projections, calling into question the validity of the approach from an efficiency point of view.

Perhaps the most serious disadvantage of this approach is the necessity to completely model every aspect of a project. While this technique may potentially eliminate many of the on-site decisions resulting from incomplete information in traditional drawings, it eliminates the possibility of serendipity in design during the construction process.

Benefits and Future Work

The major benefits of this technique are derived from the three-dimensionality of the approach. There is enhanced visualization of the building and the assemblies, reducing the interpretive process by the contractors. There is the possibility to prefabricate much of the assembly since many of the integrative problems would have been explored in the computer-based model. The ability to develop more accurate cost analysis exists since individual components can be counted and difficult assemblies can be detected in advance. There is also the possibility to develop self-help, or "how-to" teaching videos/programs utilizing this technique.

Future work will include the integration of component modeling for the teaching of construction technology in both a classroom environment as well as a laboratory setting. Work also continues on the custom tailoring of a generic modeling system to improve component construction and manipulation. The goal is to develop rules for the automatic generation of components, and to develop an "intelligent" system that facilitates the digital construction the building. Ideally, portions of the digital model and each component would be linked to a database that could be queried for dimensions, product information etc., thus eliminating the "freezing" of one view of the model and annotating it.

As a final note, it is important to mention that while all the images presented are axonometric views of the model, this technique does not rule out traditional projections such as plans and elevations. Based on this effort, it is clear that flat projections are necessary and preferred in many instances. These views can be simply cut from the component model as easily as the axonometric views, but were not chosen in order to explore the ramifications of the three-dimensional method of building description.
References


