THE VIRTUAL BUILDING - THE IMPLICATIONS OF ITS PREPARATION DURING THE DESIGN PROCESS

The virtual building and the design process

A.D.DAWSON
Deakin University, School of Architecture and Building, Geelong, Australia

Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 2930-2938.

Abstract

This paper examines the impact of the preparation of the virtual building as an outcome of the design process. The implications for the design practitioner working in an environment in which a virtual building model is prepared and tested prior to commencement of construction are discussed. Changes to the current organisational structure of the design process are suggested if a move is to be made toward an integrated virtual building construction and performance modeling environment.

Keywords: Virtual building, design process, communications, integration

1 Introduction

Traditional methods of project procurement in the building industry are based on a clear separation of the design from the construction process. This occurred during the eighteenth century when the diversity of skills and technical complexity of construction became too great for the craftsman to carry out both design and construction as had been done previously (Saint 1983). Architects then emerged from two discipline areas. One from the arts based amateur designers and the others from at least a background in the building trades. The development of the art - architecture as a distinct profession was based on the exclusion of '…surveyors, measurers and those with interests in the building trades…' (Saint 1983, p.61). The legacy of this foundation is evident throughout the development of the RIBA and the maintenance of the current separation of the architect as designer and the master builder as the contractor. This separation of design from construction or manufacture has also been the focus of other manufacturing industries since the development of mass production after the industrial revolution (e.g. Womack et al. 1990).

The recent reevaluation of the relationship between design, manufacturing, product quality and lifecycle has lead to the development of the concept of concurrent engineering. This is the '…systematic approach to the integrated, concurrent design of products and their related processes including manufacture and support' (Rammig and Steinmüller 1997). High levels of integration identified as being so critical to the implementation of concurrent engineering is facilitated by the use of information technology and in particular computer-aided design (CAD) (Hartley 1992). Without CAD systems and integrated performance simulation packages, the level of resolution and pre-manufacture testing of a proposed design is less likely to fulfill the promised outcome of increased product performance and quality associated with more economical and efficient manufacturing.

The construction industry has developed a system of operation which, despite the developments in information technology, has not changed significantly over recent years. This has resulted in the industry developing a reputation for poor productivity and performance. This is in contrast to other industries that have tended to view IT as at least one of the mechanisms for increasing competitiveness and product quality (e.g. Johansson 1996). While the building industry may be seen as unique in so far as it deals with one of a kind construction, there are manufacturing sectors, such as shipbuilding, which have very similar limited production run operating environments. These see the use of IT, in particular virtual performance evaluation and assembly, as a means of increasing the predictability and reliability of the outcome of one of a kind manufacturing processes (e.g. Ouillette 1994; Tatum et al. 1994; White 1990).

By more accurately forecasting both the applicability of procedures to be used in the construction process and the performance of the completed constructed object, the predicted financial commitment becomes increasingly reliable with a subsequent reduction of overall risk in undertaking a project (e.g. Bennett and Lamb 1996). Virtual building project modeling has the potential to be a mechanism for such forecasting in the construction industry.

The impact of the development and implementation of the virtual building project as part of the design process is likely to have a profound impact on the construction industry. This has the potential to significantly influence the way buildings are designed, how the design intent is communicated and the means which are used to support the construction and lifecycle maintenance process. However, the transition to this may be problematic, particularly for architectural practices.

2 Outcome of current documentation in traditional procurement

The outcome of the culmination of the design and documentation process is a set of contract documents consisting of working drawings (including those supplied by specialist consultants), specifications and a written contract. The description contained in these documents is that of an idea for a three dimensional object transformed into a two dimensional medium from which a three dimensional object is to be constructed (Figure 1). The building as a three dimensional object generally exists in the mind of the designer, although possibly not in the mind of the client (Cuff 1992), and is communicated to the builder using a two dimensional medium. There is therefore a great reliance in the experience of the designer in being able to visualise the building as a three dimensional object and then translate that vision into a two dimensional medium. As buildings become more complex in design, construction and servicing, this becomes more difficult. At its most complex, it may be impossible for any one individual to fully understand a building in its entirety.

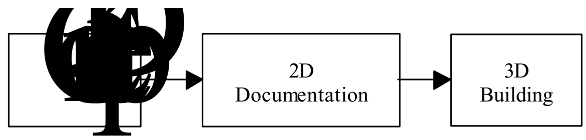

Fig. 1: Design concept transformation

2.1 Representation

The outcome of the architectural design process is a set of 2D documents which aim to communicating the design intent, but which do not fully describe the building as it is to be built. Rather, they are prepared in a shorthand language that is generally understood by the various participants in the construction industry. The interpretation of the documents is based on a set of conventions, knowledge of which is built up over years of participation in the industry. The language has been defined (Standards Association of Australia 1985), however it does not attempt to fully describe any building and simply seeks to standardise the vocabulary and interpretation of the language used. For example, the documentation prepared for Australian brick veneer construction does not show timber studs at 450mm centres although there is a clear, and universally assumed, intent that they should be placed where required (Figure 2).

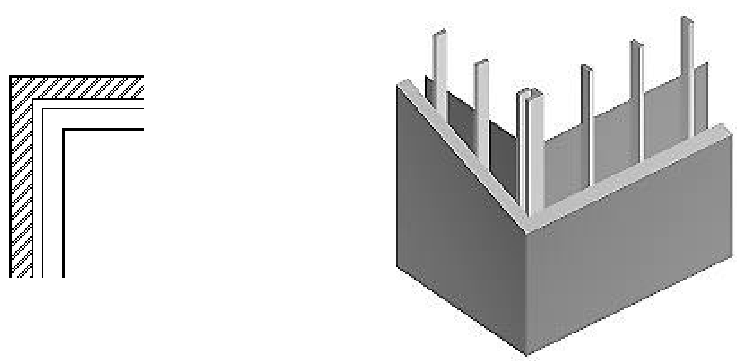

Fig. 2: Documentation vs. meaning

Detailed resolution of a design prior to finishing the documentation is therefore not required and a complete and comprehensive description of the building is not assumed to be provided (at least by the building contractor, although it may be by the client). The documentation as prepared therefore uses a graphic language that does not assume that a fully complete description of the building is even intended to be provided. It is apparent that, despite the incomplete documentation, the intent is that a complete, stable and usable building is to be constructed. Anecdotal evidence suggests that the closer a set of documents approaches a full description of the building the higher the contract price is likely to be. This is a clear disincentive to thorough documentation and, by implication, thorough resolution of the design. The apparent danger of over documentation is a factor architects appear to be conscious of. Builders do not expect a full building description nor necessarily see it as desirable as it tends to reduce the flexibility in how they undertake the construction process.

2.2 Definition of responsibility

In the preparation of the documents, the issue of responsibility arises. There is a clear definition of responsibilities during the design and construction process. Each sector of the industry attempts to ensure that they are not responsible for another's contribution over which they have little or no control or knowledge (RIBA 1991). This has a significant impact on the nature of the documentation as prepared. Each consultant, such as the structural or mechanical engineer, prepares separate documentation for their area of responsibility. Architectural drawings seek to define the overall building form and coordinate the various sets of consultant's documents (Figure 3).

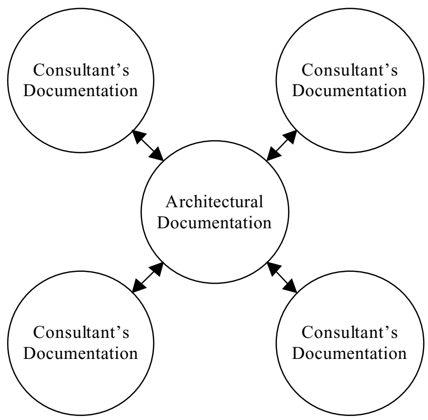

Fig. 3: Relationship - Architectural to consultant's documentation

In the traditional method of procurement, this separation of responsibility carries through to the construction process, the details of which are determined by the contractor after design and documentation is complete and tenders are let. Not only is detailed resolution of the construction process not required during design and documentation, in the traditional form of architectural service it would be encroaching on the responsibility of the builder (RIBA 1991). It is therefore the architect's role to coordinate the preparation of a description of what is to be built not define how to build it.

This requirement for clear definition of responsibility encourages fragmentation and compartmentalisation of information that is used to describe the building that is to be constructed. The seamless integration of information in order to describe the building as a whole is therefore discouraged and information *silos* are created. This is characteristic of a sequential engineering process which has created difficulties in manufacturing and has led to the development of concurrent engineering (Prasad 1995).

2.3 Visualisation

The purpose of design visualisation is to communicate the visual and spacial quality of the design intent. However, it brings with it its own limitations related to the scope of information that is necessary to include in the building model from which the visualisation is developed. When preparing a virtual building model as a visualisation tool, two elements only are required:

- geometry of visible surfaces
- visual properties of visible surfaces (e.g. texture pattern, colour, reflectivity)

It is apparent that the amount of information embedded in a 3D model, which describes a building for this purpose, is not complete. It clearly does not approach the complexity of that which is necessary to describe a building in any comprehensive manner. In addition, the model may only require a small part of the building to be described and may be analogous to that of a movie set in which only the visible parts of the form need to be shown any concern.

The 3D model prepared for design visualisation is therefore lacking information that would make the model usable for any other purpose. Thus, it excludes information such as thickness, location and composition of subsurface materials. These have a critical impact on the overall performance of the building as a complete operational system and are necessary if any performance analysis is to be undertaken using the prepared building model. The current 3D models, which may be developed as part of the design process (Dawson 1996), require substantial additional elements, both geometric and not geometric, if they are to be utilised as anything other than a presentation or visual design evaluation tool.

3 Design within a virtual modeling environment

Design development support systems and methods of communication operating within a virtual modeling environment are under development in industries other than construction and contrast markedly with those described above. These include aircraft design (e.g. Business Week 1991), automobile manufacture (e.g. Van Niekerk 1995) and shipbuilding. Of these, shipbuilding is potentially of the most interest with limited series production (down to one of a kind) of technically complex large scale objects manufactured from simple components (Johansson 1996). Some ship designs may be likened to small cities with infrastructure including restaurants, hotels, and HVAC systems and, with the exception of hull structures and propulsion units, may be very similar to buildings in their architectural requirements.

The development of virtual design support systems is resulting from the application of concurrent engineering to ship design and construction. The shipbuilding industry, particularly in the United States, has seen the development of concurrent engineering as a means of increasing competitiveness (Bennett and Lamb 1996). Key concepts which have developed from this have been the carrying out of design, performance testing and construction process evaluation before manufacturing commences (e.g. Ouillette 1994). This has benefits in increasing the predictability of the performance of both the construction process and the completed product. That in turn reduces the financial risk associated with the design, construction and operation process.

The development of 3D CAD models as a means of validating design decisions related to complex control or machinery spaces has been carried out. This has been demonstrated to be of clear, if qualified, benefit (Tatum et al.

1994). However, this is little more than design visualisation as an alternative to constructing full scale mockups. The greatest opportunities are potentially the development of complete product models from which relevant and appropriate information can then be extracted as required.

The product information model (Figure 4) has been proposed as a single source of information to support the design development and evaluation process (Johansson 1996).

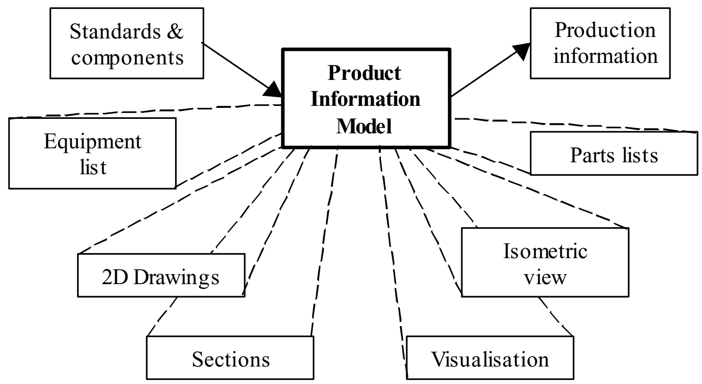

Fig. 4: The product information model (after Johansson 1996)

The model contains both geometric and non-geometric information. Stored non-geometric information includes such data as weight, surface treatment and energy consumption. In addition, it also identifies connections and dependencies between objects. Although the product model does contain geometric information and visualisations can be generated, its primary focus is on the non-geometric data. The complexity and extent of the non-geometric data is clearly recognised. With this level of embedded information, the product model becomes a rich source of data for further development of performance, construction or lifecycle maintenance simulation.

There are two key elements which facilitate the implementation and success of concurrent engineering and subsequent development of product models and virtual performance simulation in shipbuilding:

- a design/build organisational structure in which the client approaches a shipbuilder who then carries out all operations from initial briefing to completion of construction and possibly maintenance and refit. A design may be developed specifically for a client's needs or may be purchased from a naval architect and then modified by the shipbuilder's own design office.
- the continuity of organisational structure from one design/construct commission to another where long term continuous relationships are established between the players in the design and manufacturing process. These include design engineers, external suppliers and sub-contractors, shipyard workers and possibly the client.

These elements give a level of cohesiveness and stability that are not available to organisations that are fragmented and transitory.

4. Product information model for construction – the virtual building

Information models developed within the construction industry are characterised by a focus on the transfer of information between players within the industry (IAI 1997; Anumba et al. 1997) (Figure 5).

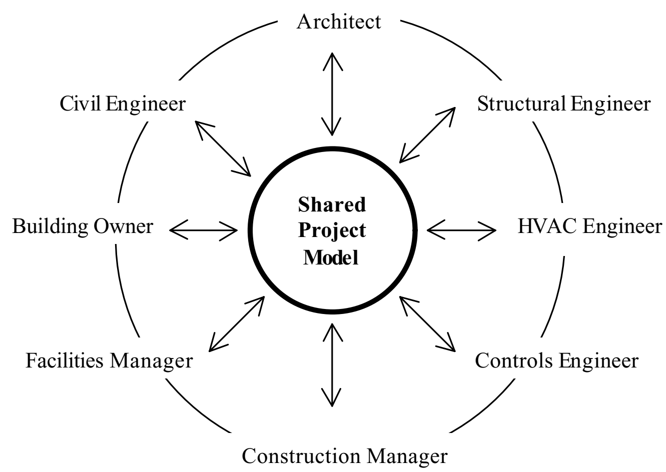

Fig. 5: The shared project model (after IAI 1997, p. 2)

For a fragmented industry, an emphasis on the seamless interchange of information is attractive. This facilitates the electronic transfer of design and construction information across multiple computer platforms and CAD systems. However, the shared information model does not necessarily lead to the level of integration that other industries perceive as being important for increasing product quality and manufacturing efficiency through virtual model development and testing of design proposals.

The level of information density contained in the virtual building model should allow the following to be carried out:

- design validation from a visual, spacial and functional perspective
- performance simulation both before, during and after completion of construction
- construction process simulation

The virtual building, which is developed based on these concepts, is required to embody the total definition of the building. It is therefore required to contain the following (Dawson 1998):

- comprehensive information about the building form and geometric relationships between assemblies of components
- geometric information about the individual components used to make up the component assemblies
- comprehensive information about the graphical and nongraphical properties of component assemblies
- comprehensive information about the logical relationships between components and component assemblies

The ability to undertake this level of testing both during and after development of a virtual built environment introduces the concept of simulation based design to the development of the virtual building.

5 Discussion and conclusions

It is apparent that the methods of building design operation, which culminate in the current contract documentation, lead to:

- incomplete resolution of the building as a three dimensional object
- incomplete resolution of the building detail as it is to be constructed
- documents used to communicate design intent being incomplete
- reliance on others in the construction process, such as contractors or sub-contractors to determine how to build a completed (although not complete) design
- fragmentation of design information across multiple disciplines
- fragmentation of responsibility where unambiguous definition of boundaries and responsibility is often difficult

This results in a focus on who wants what information rather than on what information is required in order to most economically and efficiently construct the building or its parts so that it will perform in a predetermined manner over time.

Two elements characterise the virtual building, its completeness and its homogeneity. The virtual building is prepared so that it can be analysed in a manner that replicates a set of performance experiments on an actual building. These range from analysing virtual assembly methods to determining the impact on energy consumption of alternative methods of refurbishment. In the virtual building there is no separation of element description based on responsibility. There should be no information about the design that exists solely in the mind of an architect or contractor.

The current structure of the construction industry, the particular relationship between its players and the method of communication, preclude the development of product information models or their extension, the virtual building.

The development of the virtual building requires availability of all major participants in the design and construction process from initial client contact. This ensures that the model that is being developed through the design process is complete and fully reflects what is planned to be built. Major changes are therefore necessary in the structure of the design sector of the building industry:

- designers will be required to offer clients complete packages of service from pre-design to maintenance, involving contractors and suppliers
- long term relationships need to be developed between designers, contractors and suppliers
- designers will be required to place emphasis on complete design resolution before construction commences
- designers will be required to seamlessly integrate information from various consultants into a single project information model (or its successor, the virtual building model)

Ultimately, the outcome of the design process will be the preparation and testing of the proposed design through the development of a virtual building model, not the preparation of 2D contract drawings or 3D visualisations.

Whether these are initiated by architects, as the traditional coordinators of the design process, or project managers, as suggested through the application of concurrent engineering to the design and construction process (Love et al. 1998), remains to be seen. However, it is currently not clear whether designers will be able to make the transition from their current fragmented methods of operation to one in which there is an emphasis on quality, predictability and efficiency of outcome for all concerned.

6 References

Anumba, C.J., Baron, G. and Evbuomwan, N.F.O. (1997) Communications issues in concurrent life-cycle design and construction, *BT Technology Journal*, Vol. 15, No. 1. pp. 209-216.

Bennett, J.G., Lamb, T. (1996) Concurrent Engineering Application and Implementation for U.S. Ship Building, *Journal of Ship Production*, Vol. 12, No. 2. pp. 107-125.

Business Week (1991) Boeing Knocks Down the Wall Between the Dreamers and the Doers, *Science and Technology Section*, October 28.

Cuff, D. (1992) *Architecture: The Story of Practice*, MIT Press.

Dawson, A. (1996) *Computerisation of Architectural Practices in Victoria, Australia.* PhD Dissertation, Deakin University.

Hartley, J. (1992) *Concurrent Engineering*, Productivity Press.

Johansson, K. (1996) The Product Model as a Central Information Source in a Shipbuilding Environment, *Journal of Ship Production*, Vol. 12, No. 2. pp. 99-106.

IAI (1997) *IFC End User Guide, Industry Foundation Classes – Release 1.5*, International Alliance for Interoperability.

Love, P.E.D., Gunasekaran, A. and Li, H. (1998) Concurrent engineering: a strategy for procuring construction projects, *International Journal of Project Management*, Vol. 16, No. 6. pp. 375-383.

Ouillette, J.J. (1994) DDG-51 Class Computer-Aided Design, *Naval Engineers Journal*, July. pp. 165-173.

Prasad, B. (1995) Sequential versus Concurrent Engineering – An Analogy, *Concurrent Engineering*, Vol. 3, No. 4. pp. 250-255.

Rammig, F.J. and Steinmüller, B. (1997) CE – Enabling Technologies, in *Concurrent Engineering*, Medhat, S. (ed.), Research Studies Press Ltd. pp. 33-60.

RIBA (1991) *Architects Handbook of Practice and Management*, Royal Institute of British Architects.

Saint, A. (1983) *Image of the Architect*, Yale University Press.

Standards Association of Australia. (1985) *Technical Drawing Part 301 – Architectural Drawing*. SAA, Sydney, AS 1100, Part 301 – 1985.

Tatum, S.A., Byrum, J.C. and Rourke, P.W. (1994) Design Validation Using Computer Models in Lieu of Full-Scale Mockups, *Marine Technology*, Vol. 31, No. 3. pp. 225-230.

Van Niekerk, B. (1995) 3D CAD Models and Concurrent Engineering, *The South African Mechanical Engineer*, Vol. 45, November/December. pp. 9-11.

White, C.V. (1990) Harnessing Simulation for the Naval Shipyard, *Journal of Ship Production*, Vol. 6, No. 4. pp. 207-211.

Womack, J.P., Jones, D.T. and Roos, D. (1990) *The Machine that Changed the World*, Rawson Associates.