A DIGITAL PROCEDURE OF BUILDING CONSTRUCTION

A practical project

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Abstract. The process of building electric-mechanical design held only by shop drawings now. The physical models were rarely used in this field. This research is combined with two practical building projects, following the progress of construction by using digital models and animations to simulate the structural layouts of the projects. This paper foresees that digital models will become an indispensable tool for building electric-mechanical design, in the near future.

1. Development of Design Media

In earlier times in which computers have not yet been developed well, there has been some researches regarding representation using conventional media (Gombrich, 1960). For ancient architects, the design process was described abstractly by text (Hewitt, 1985); the process evolved from unselfconscious to conscious ways. Till the appearance of 2D drawings, these drawings could only express abstract visual thinking and visually conceptualized vocabulary (Goldschmidt, 1999). Then with the massive use of physical models in the Renaissance, the form and space of architecture was given better precision (Millon, 1994). Researches continued their attempts to identify the nature of different design tools (Eastman and Fereshe, 1994).

Simon (1981) figured out that human increasingly relies on other specialists, computational agents, and materials referred to augment their cognitive abilities. This discourse was verified by recent research on conception of design and the expression using digital technologies (McCullough, 1996). While other design tools did not change as much as representation (Koch, 1997), the involvement of computers in conventional architecture design arouses a new design thinking of digital architecture (Liu, 1996; Krawczyk, 1997). The notion of the link between ideas and media is emphasized throughout various fields, such as architectural education (Radford, 2000; Madazo, 1999), Internet, and restoration of historical architecture (Potier et al., 2000).
Information technology is also an important tool for civil engineering projects (Choi and Ibbs, 1989; Johnson and Clayton, 1998). Compared with conventional design media, computers avoid some errors in the process (Zaera, 1997). However, most of the application of computers to construction is restricted to simulations in building process (Halpin, 1990). It is worth studying how to employ computer technology meaningfully to bring significant changes to concept stage during the process of building construction (Madazo, 2000; Dave, 2000) and communication (Haymaker, 2000; Maher, 2000).

2. Problem and Objective: Design in Engineering

The traditional approach involves the use of drawings and models as a means of representing the basic conception (Mitchell, 1997). The type of models used in this process can be classified into physical models and digital models (Lin, 1999). Both of these two types were used as a means of solving the kind of complex problems that two-dimensional drawings were unable to handle. Piping as it is used in the mechanical and electronic engineering is such a kind of very complex problem. Today, shop drawings are the only means of analyzing and communicating such design conception. It is intended that this paper examine and discuss those stages of the design process relating to electric-mechanical engineering with the intention of discovering whether or not 3D models have an important role to play.

It can be seen that the physical model was rarely used. The extreme complexity of piping as used in the electric-mechanical engineering, means that producing physical models is not economically viable, and as such wastes human and financial resources, as well as time. As past experience has revealed these shortcomings to us, this paper will not provide any research or discussion concerning the use of the physical model in the electric-mechanical design. Taking into consideration the extent to which digitization has led to the common use of digital models in such areas of design as structural design, exterior design, and interior design. This paper will consider the question of whether or not problems concerning the feasibility of computer simulation in the electric-mechanical engineering design must first be solved before it can be used as a method of design. In order to help to answer this question a warm up experiment was undertaken.

3. Methodology: Design Process

In order to prevent a situation whereby computer-generated design might influence the final shape of the shop drawings, we selected a case in which such drawings had already been completed. The construction site chosen is
located in Taipei, Taiwan, and comes under the building type classification of “office building”. The air-conditioning pipe system and the electrical system were chosen as the elements that would undergo the process of computer simulation. We built the simulated models according to the shop drawings, and them one at a time. The information supplied by the shop drawings was never sufficiently comprehensive to allow us to obtain a fully comprehensible picture, we needed to frequently confer with the designers of the shop drawings, as well as make frequent inspections of the site. After applying computer simulation techniques to the electric-mechanical design, we began to actively undertake the process of design using this medium.

3.1. TRADITIONAL PROCEDURE

Later we will provide an explanation of our plan, which is to integrate the use of the computer in the entirety of this design process. But it would be best to first outline the procedures traditionally used in Taiwan to produce the shop drawings for the electric-mechanical design. When the architect assigned to a project has completed all of the architectural design work, he then produces drawings showing the way the various elements of the electric-mechanical design, such as the plumbing, the air-conditioning pipe, the electrical systems. As is the case with preliminary sketches in general, in this phase the positioning of the piping is still highly ambiguous, showing that the exact measurements is a matter that has yet to be decided. Moreover, the task of layering these drawings has yet to be undertaken. The analysis and inspection of how the various systems will relate to each other has also yet to be undertaken, and also yet to be completed are the adjustments made to the positioning of these various systems in respect to the ways they will relate to each other. As a result, the designs of these various systems are usually at variance with one another in this phase of design. These tasks are instead given to the electric-mechanical office to complete.

After receiving the relevant drawings, the electric-mechanical office begins task of layering the drawings depicting the various systems. Then in respect to the design of each of these systems, as well as the design conflicts existing between the various systems, make the adjustments needed to erase these design conflicts. After all the necessary adjustments have been made, it then attaches precise and detailed measurements to each of the drawings, thus fully completing the task of drawing up the set of shop drawings. It should be emphasized here that the procedure described above differs from the approach taken by designers in other parts of the world, but it nonetheless describes the way such is actually handled in Taiwan. From the point of view of the amount of insight gained, this is the part of the real project that has been most valuable to us and contributed most to our knowledge.
3.2. DIGITAL PROCEDURE

Because of the intricacies of the relationship existing between the architect office and the electric-mechanical office, the timing of the procedure whereby computer design was to be introduced into the process became of paramount importance. For this reason, we selected a project located in Min-Chuan East Road in Taipei, allowing us access to information concerning the schedule. The building type was classified as being a “factory” and this project were supplied by Phoenixtec Group Ltd. The main source of motivation being that the computer simulation would reduce mistakes made during construction as well as improves the quality.

After the architect had completed all of the architectural drawings, we began to build the mass model of the building using computer, and at the same time the architect began the initial process of fitting together the various system of the electric-mechanical engineering. After the electric-mechanical office received these early-stage-design drawings from the architectural office, our formal cooperation with that office first began, and from here we began work on the detailed design of the electric-mechanical system. Most of the time spent by the designers in the electric-mechanical office was accounted for by the design of 2D drawings, work which included eliminating design conflicts within the system, and deciding on the exact positioning of the piping. Up into this time, all of the design analysis done by the designers had relied on these 2D drawings. Following the completion of the shop drawings we began to construct 3D digital models using these drawings as a source of design information, just as we had done in the previous warm up experiment. It is important to point out here that construction work on the construction site had already begun and that the builders were relying totally on the use of these 2D shop drawings. However, as we continued the process of producing 3D digital models, we discovered that there existed several problems that the electric-mechanical office had left unsolved. Shop drawings depicting individual systems isolated from the network of systems as a whole seemed not to show any inconsistencies, but when they were fed into computer simulations of the virtual architectural structure, inconsistencies began to appear. While working on the site, the builders discovered the existence of these problems. As a result, a channel of communication between the 3D models, the 2D shop drawings, and the construction site, was opened up. Under the guidance of the channel of communication thus established, the installation of each system, as well as construction of each floor of the building, was implemented, continuing until both the digital model and the physical building had been completed.
4. Results and Discussion

The main theme of this paper concerns the ways in which digital models can help to solve problems that arise in the construction process, and in particular it is focussed on those problems that have arisen as a result of the limitations imposed on designers by design media. The following three cases were chosen as being most representative of the totality of those encountered during the project. Such cases will serve as an illustration of how computer media, the designer, and the constructor can function in tandem to establish a basis for accurate design and construction, and in respect to these cases this paper will also provide some discussion concerning the feasibility of design ideas.

4.1. THE ELECTRIC SYSTEM

In conveying electricity from a point exterior to the building to the interior of the building, the central meter is given total control over the flow of current. In the case of the building discussed below, the central meter has been equipped with 24 pipes, and these pipes connect up to the eight sub-meters in the building. Each of these eight sub-meters controls a separate floor, and to do this each of these sub-meters must have three outgoing pipes connecting to a cable tray (Figure 1). The cable trays have been assigned the role of distributing electric cable to the various levels of the building. Regulations concerning architectural practice state that the distance separating the cable tray from what is below it must be at least 220 cm. Each of the sub-meters must be positioned underneath a beam, and the three outgoing pipes have to make effective use of this space between the cable tray and the beam to effect a connection (Figure 2). And the design of this arrangement must not conflict with the layout of the 24 pipes.

From the description given above it can be seen that the following areas of design and questions must be given careful consideration: 1. The level of building element and the relationship of element to other element. 2. How the incoming and outgoing pipes are to be connected up to the sub-meters. 3. Will the work of construction be difficult or not. 4. Will the finished work be aesthetically pleasing. It can be seen that if we look at something as complex as designing a building’s electric system, the shop drawing is not able to adequately deal with the problems that the designer is likely to encounter. The fact that the construction staff actually took the initiative to ask us for design help provides further evidence of the inadequacy of the shop drawing. The digital model is able to create a gravity-free simulated architectural environment, and can provide the designer with any combination of differing spatial arrangements. It is also an invaluable reference tool in the hands of specialized construction staff. It can thus be seen that not only do the 3D
digital models overcome the shortcomings of the 2D drawings, it can also work to overcome the limitations of the 3D physical models.

Figure 1. The electric system  
Figure 2. Space between the tray and the beam

4.2. THE AIR CONDITIONING SYSTEM

In this case cold water is circulated around the building to act as an air conditioning system. The system is divided into incoming pipes and discharge pipes, together forming the two main system of circulation. The main pipes of the two systems must be connected to the same twenty air-conditioning units (Figure 3). In order to ensure the flow of water is not impeded or blocked, the each main pipe must have a large diameter on one end and a small on the other end. Additionally, as well as being constrained by the height of the factory building, the pipes must be able to pass through the building’s beams. Thus the task of designing such a system is clearly a hugely difficult undertaking. However, to show the way in which the main pipes fit together with the branching pipes, the shop drawings only displayed an overly-simplified cross shaped intersection, making it necessary for construction staff to rely on their own mental calculations to devise a way to fit the two systems together. Design work done with a digital model eventually came out with a “spiral shaped” solution to the design problem presented by the air-conditioning system (Figure 4).
4.3. THE CABLE TRAY SYSTEM

As was discussed in case 1, the main function of the cable tray is to distribute electric cable to the various levels of the building. Thus the cable tray system must be designed in a way that allows for abrupt changes in horizontal/vertical direction. In this particular case, three cable trays used to distribute the electricity cables, displayed a design conflict problem relating to a conflict of levels at the junction determining this abrupt change of direction. And after reaching this junction the three cable trays had also to be positioned in an ascending direction towards the floor above them. Thus a solution to the levels problem had to be found, as well as to the problem of ensuring that in the abrupt 90 degree changes in horizontal and vertical direction (Figure 5), the three cables would maintain a set distance from one another. The information supplied by the shop drawings was highly ambiguous, forcing the construction staff to tax their imaginations to the limit in solving what presented itself as an extremely thorny problem. After a considerable amount of discussion it was decided to lift the height of the cable tray that was causing the design conflict by 10cm. And a digital model was used to simulate the 90-degree horizontal and vertical changes in direction that the three trays needed to make in finding a path through the building (Figure 6).

4.4. DISCUSSION

Electric-mechanical design forms only a small part of architectural design as a whole. And for this reason the pressure of time plays an important role in the work done by the designer. People often pay too little attention to the detailed stages of design work. In the process of electric-mechanical design by far the most commonly used design media is the shop drawing. All of the design components are represented in a highly symbolic and abstract manner, and the organization of the inter-relationship of these components is presented in an
extremely simplified way. Symbols, or lines laid out in abstract sections, are placed in a geometric relationship to each other so as to barely give expression to the actual relationships existing between these components. Presenting design information in such a highly abstract and symbolic form creates a situation in which the functional content and three-dimensional form of the various components is expressed in a very unclear manner. As a result, design problems often remain undetected during the design phase of the project. During the construction phase, however, construction staff must expend a good deal of energy in seeking solutions to these problems, which as well as wasting the time of construction workers, also leads to poor quality work. As well supplementing the shortcomings of 2D media, digital models in respect to vertical dimensions, can also make use of simulated space to unify separate elements of the design into a single unified structure. Moreover, by detecting the problems hidden in 2D drawings, digital models can significantly increase the quality of finished construction work. Of course, it is possible to deal with the limitations of a 2D drawing by producing layered drawings, but the complexity of this task put its beyond the imaginative scope of the human mind (Figure 7).

Figure 5. The cable tray problem  
Figure 6. Solution on the construction site  
Figure 7. Highly symbolic and abstract representation of shop drawings
5. Concluding Remarks

It is not difficult to produce a mental picture of the hierarchical relationships existing between the various elements as they exist in simplified form. But if any degree of complexity is introduced into the picture, we are then forced to rely on purely imaginative methods in order arrive at an understanding of complex spatial relationships. The work of installing the electric-mechanical fixtures means that the builder must deal with an extremely complex set of structural relationships, and taking into account the degree of precision demanded, it is extremely difficult for him to arrive at design solutions using his imagination only. Before beginning construction work, a complete design and set of designs must be produced, and 3D digital models are able to produce more precise and better able to communicate designs than those produced by traditional shop drawings. They can also fill in the gaps produced by the limitations in the imaginations of on-site builder and engineers, produce more accurate design work, and create a virtual world by which to communicate ideas.

Of course physical models can also increase design accuracy, and can also supplement the shortcomings of 2D media. However, to compare physical models and digital models, we see that digital models lack the drawbacks of weight and physical presence, whilst being more nimble and flexible in their ability to create many and varied simulated designs. In the field of building electric-mechanical design, such qualities are extremely important, and thus physical models are clearly lacking in this respect.

Although the physical models were rarely used in the field of building electric-mechanical design, this paper foresees that three-dimensional models will become an indispensable tool for building electric-mechanical design, in the near future. Digital models will begin replacing physical models, and occupy the process of building electric-mechanical design, now held only by shop drawings.

In respect to the discussion and research supplied by this paper, the examination of the role played by the shop drawing in architectural design is only a beginning. The sheer breadth of the area focussed on, the construction of buildings, means that it was impossible to discuss every detail, but this limitation should provide ample scope for further research.

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