Chapter 5

Conclusions and Recommendations

5.1 CONCLUDING REMARKS

A major contribution of this study is the development of a practical automatic design tool for the optimal conceptual design of high-rise office buildings subject to given client/user requirements and governing design regulations. Specifically, the computer-based tool has the capability to account for architectural, structural, mechanical and electrical systems and graphically identify optimal trade-off relationships between capital cost, operating cost and income revenue. The information can be used to guide and balance the concerns of the various participants involved in the building design, including the financial concerns of the owner, the enclosure and spatial concerns of the architect, the load-carrying concerns of the structural designer, and the heating, ventilation, air conditioning, elevator and lighting concerns of the mechanical and electrical designers. The computer-based procedure has the additional capability to account for life-cycle costing and predict the potential for different conceptual design scenarios to become profitable over time, which is of particular interest to building owners.

While only buildings with simple rectangular layouts were considered by this study, the developed conceptual design procedure is based on a mathematical model for multi-criteria optimization that is independent of the complexity of the building, and it is readily possible to account for all manner of additional design considerations and features, such as irregular layouts, multiple cores, lobbies, atria, mezzanine floors, foundations and underground parking.

The computer-based multi-criteria genetic algorithm is capable of searching huge design spaces very efficiently; e.g., while the data in Table 3.1 allows for more than 11.5×10^9 different conceptual design scenarios (albeit, many are infeasible), a single run of the MGA for each example office building only needed to consider about 0.0013% of them before converging to a Pareto-optimal design set. For the design examples presented in Chapter 4, one run of the MGA required 4.5 hours on average to execute on a 266 Pentium II computer (i.e., the examples each took approximately 13.5 hours on average to complete three runs of the MGA to find the combined overall Pareto-optimal design set). On average, rapid and steady convergence to the final Pareto optimal design set was achieved in less than 200 design cycles, independent of the different input parameters prevailing for the different design examples. Furthermore, other studies not reported herein have found that the number of Pareto-optiamal designs is apparently independent of the initial population size selected to commence the design process, and that the MGA is only weakly dependent on the number of design variables. It should also be noted that the computer times can be significantly shortened by using parallel-processing technology to exploit the inherently parallel nature of the numerical calculations for Pareto optimization using adaptive genetic search

A major benefit of the computer technique for the optimal conceptual design of office buildings is its capability to identify economical designs. Economy is achieved from two viewpoints. First, conceptual designs are found that each have the characteristic that no other feasible design exists that dominates it in the sense of having lower capital and operating costs and higher revenue income. Second, another meaningful saving for the design team is in the time and cost required to produce a number of conceptual design worthy of further investigation at the subsequent preliminary design stage. Unlike the traditional trial-and error analysis/design method, which typically requires a great amount of time for a competent design team to identify best-concept designs for a high-rise office building project, the automatic conceptual design tool developed by this study is capable of reducing the design time for the same project to a matter of hours.

Once the Pareto-optimal design set for an office building has been found, computer color filtering can be employed to immediately identify the prevailing trade-off relationships existing between cost and revenue for any number of different architectural, structural, mechanical and electrical parameters for the building; e.g., for the structural type, story number, bay area and window ratio parameters considered by this study, and for other parameters such as floor type, window type and, when multiple choices exist, for HVAC, elevator and lighting systems. Moreover, different Pareto-optimal design sets can be found for an office building to investigate the influence that different cost and revenue indices have on the conceptual design solution; e.g., the design examples presented in Chapter 4 demonstrated that changes in land costs and material-dependent construction costs can significantly alter the preferred choices of the architectural and structural systems for a building.

The color graphics identifying optimal trade-off relationships between cost and revenue for an office building are even more comprehensible when they are observed on a computer screen, where they can be readily manipulated for viewing at any angle (e.g., see Figures 4.6 to 4.9 and 4.17 to 4.18). These computer-generated graphics can provide experienced architects and design engineers with comprehensive integrated cost-revenue information that they may otherwise only know and understand as disconnected facts and rules. These results also can serve as an educational tool to augment the knowledge and understanding of novice architects and design engineers.

Finally, while this study has focussed on office buildings and corresponding cost-revenue criteria, the proposed mathematical model for conceptual design is independent of problem type and is readily applicable to any type of artifact and related objective criteria. The computer-based procedure will create viable conceptual design scenarios and informative 2-D and 3-D color graphics identifying optimal trade-off relationships between conflicting objective criteria, even when the number of criteria is greater than three.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

While the computer-automated design procedure developed by this study is a useful tool for the conceptual design of regular rectangular high-rise office buildings, it is recommended that the following future research areas be pursued to further enhance the capability of the procedure and to broaden the range of applicability to building design.

1. Building Shapes and Setbacks

   Due to architectural aesthetics and city restrictions, modern high-rise buildings are often found with different shapes and set backs. It is suggested that the developed conceptual design tool be further enhanced to account for setbacks that change the size of the floor plan over the height of the building, as well as to account for floor plan shapes other than rectangular (e.g., circular, triangular, etc.).

2. Design Criteria for Structural System

   The design criteria used in this study were primarily based on strength (stress) concerns, with stiffness (strain) concerns only being met by applying a limitation on the slenderness ratio for a building so as to control lateral sway. It is recommended to develop a formal stiffness check to evaluate each design for lateral deflection, so as to assess more completely the applicability of different structural systems. Furthermore, this study only considered lateral loading due to wind. It is recommended that account also be taken for seismic loading, perhaps through approximate push-over analysis of lateral-load-resisting systems.

3. Materials

   Material strengths in this study were considered to be constant for the entire building. However, as the strength of concrete has substantially improved in recent times (e.g., 28 day cube strength of 60 MPa), more and more tall buildings are being designed with high-strength concrete in the lower story levels and low-strength concrete in the higher story levels of the building. Further improvement of the automatic conceptual design tool is recommended to account for variant material strengths for both concrete and steel construction.

4. Improved Functional Form for Space Quality

   The current study adopted a functional form for space quality that gives equal importance to both floor flexibility and occupant comfort level. Further study is needed to find a function that more completely reflects the relative importance of factors that affect space quality and, hence, lease rates (for example, to include the effect that the luxury and aesthetics of a building have on lease rates).

5. Use of Artificial Neural Networks

   The computational CPU time required to conduct a building conceptual design can be significantly reduced if, trained artificial neural networks are used to carry out repeated design activities for the various building components (e.g., finding the volume of materials, heating and cooling loads, energy consumption, etc.). This will establish the values of the multiple objective functions more quickly and result in overall reduction of the CPU time for the conceptual design process.

6. Parallel Processing

   With the recent advances in parallel computing and its availability for personal computers, it is recommended that parallel processing computing technology be employed to exploit the extensive parallel-compute nature of the developed computational procedure for conceptual design.

7. Pareto Boundary

A method for finding the boundaries of the Pareto design space was discovered in the course of this study. This discovery suggests the possibility to find only the boundaries of the Pareto space without computing the Pareto design set itself. Since the number of designs located on the boundary of the Pareto space is much less than the total number of Pareto designs, this implies that the population size and, hence, the CPU time for the MGA can be reduced, perhaps significantly. Further study in this area is recommended.