Chapter 1

Introduction

1.1 INTRODUCTION

Basic to the engineering process is the objective to develop, design and construct a system to fulfil a given set of performance requirements. Some of the objective criteria in this multi-level process are entirely rational and quantitative, but others must remain non-quantifiable because of either their enormous analytical complexity or because they involve elements of taste or aesthetics.

The fundamental aim in dealing with rational objective criteria is to find the best or optimal solution to the problem at hand. In a building optimization problem the, best solutions are those that satisfy the requirements of function and integrity for the minimum capital and operating costs and the maximum revenue income while remaining within the aesthetic bounds imposed by the architect.

High-rise buildings are an integral part of modern urban environments, and there are two fundamental differences between designing them and engineering projects of a smaller scale: 1) the consequences of design decisions are more costly; and 2) the environmental technology of a tall building is more complex. High-rise buildings represent enormous private and public investment and, most importantly, they are large consumers of resources in the form of labor and construction materials (Forwood 1975). Because of this enormous investment, research effort has long been devoted over the years to developing optimization techniques that reduce the consumption of resources for building projects (Newmark and Rosenblueth 1971, Cohn et al 1972, McDermott et al 1972, Iyengar 1973, Cohn 1995).

Like all designs, the design of a high-rise building involves the development of the physical description of an artifact subject to a set of given constraints and specifications. There are three phases in the design of a high-rise building; 1) conceptual, 2) preliminary, and 3) detailed design. Conceptual design deals with the identification of different concepts and the selection of overall best subsystems and their configurations. The preliminary design stage involves the initial development of one or a few conceptual models. Finally, the detailed design stage defines a complete solution for all subsystems, and results in final drawings for architectural, structural, electrical and mechanical systems.

Increasing numbers of high-rise buildings are produced each year for commercial use. However, most design procedures are indirect, in that a design concept is proposed and then successively analyzed, evaluated, corrected and reanalyzed until the final results fulfill the designers' demands. The success of such a design process depends very much on the initial design concept proposed and on the opinions, judgements and experience of the designers. As such, the corresponding design process is often relatively ineffective since the structural type and arrangement, architectural layout and electrical/mechanical equipment are often simply devised and copied from previous designs. Because great numbers of such edifices will be required to fulfil the accelerating demands of urban commerce, it is vital to establish comprehensive method for the design of high-rise buildings. This investigation, will focus in particular upon identifying "best concept" designs. Equally significant will be its focus on the development of a general approach by which such designs may be achieved

1.2 DESIGN OF A HIGH-RISE BUILDING

Traditionally, the architect was the master builder with control over the entire design and building process. However, in time, industrialization and increasingly complex projects have required architects to abandon areas of activity that are better served by expert engineers. Such areas in building design and construction include those related to structural, mechanical, electrical and construction engineering. In addition, the services of experts in value engineering and finance are also often required (Holgate, 1986).

The design of a project is the result of a gradually evolving concept commencing from an initial scheme generated by the design team and the owner. Initial concepts are influenced by the required functionality of the project. Further preliminary development of concepts accounting for site conditions, zoning laws and finances, structural, mechanical and electrical systems, as well as the aesthetics features of the project, eventually lead to schematic drawings. At this stage, upon approval from civic authorities, more detailed design is generated. With the input of engineers from different disciplines, the major electrical, mechanical and structural subsystems are sufficiently detailed for each team member to have information regarding the others' requirements and responsibilities, thereby enabling everyone to finalize their respective subsystem. This detailed stage is coordinated by periodic meeting among the different disciplines of the design team and involves significant communication of drawings and documents.

1.3 CONCEPTUAL DESIGN

Conceptual design is the earliest phase of the building design process and commences with a set of initial concepts. Keeping in mind that there is no single solution with optimal performance with respect to all requirements due to the fact there are conflicting objective criteria, designers must evaluate different competing criteria with the view to achieve a good compromise design. That is, the selection of a suitable solution involves making subjective compromises between conflicting objective criteria.

The conceptual design phase involves making decisions that can have the maximum influence on the final design and project cost. One study suggested that as much as 80% of the total resources required to construct a building are committed by the decisions made in the first 10% of the design process (Deiman and Platt, 1993). Albeit, designers often tend to spend most of their working time on the detailed design phase, where the scope for significant improvement is much less. They often only generate a single design concept, or at most a few that satisfy the design criteria, because traditional design practice places severe constraints on time and design costs. Extensive generation and evaluation of alternatives is only possible with the help of computer-based methods. That said, such computer methods for conceptual design are not yet available to designers in practice. One reason for this situation is that conceptual design has not yet evolved into a well-defined procedure.

An overall view of the design process and the design itself is needed when performing conceptual design. The designer at the early stages must understand the many factors affecting the building being designed. Such a global approach to high-rise building design should include account for structural efficiency, erection cost, mechanical and electrical requirements, operating cost, quality of space and comfort, and rental revenue. One should add to this list such things as initial land cost, interest on borrowed money and maintenance cost. Significant complexity comes from the need to determine the relative benefits of all of these various quantities and qualities (Rush 1986).

1.4 LITERATURE REVIEW

This literature review focuses on research concerned with computer-automated conceptual design of buildings and other civil structural entities. It is important to note that this area of research is very current and not yet well investigated and, therefore, that there are not many related documents directly available concerning high-rise buildings. Furthermore, it is necessary to mention that the researches discussed in the following do not cover all aspects involved in the global conceptual design process but do try to address the problem from several important viewpoints.

Akin et al (1988) performed automated space planning using a computer-based system called HeGel, in which the heuristic generation of floor plan layouts is based on a formal model of the architectural design process. Given an outline, HeGel generates alternative locations for design units, say a furniture set, while accounting for constraints like direct access, natural light, privacy, etc..

Baker and Fenves (1989) presented a conceptual structural design system that determines compatible structural and architectural configurations that provide the basis for subsequent analysis and optimization to find 'best' solutions.

Gowri (1990) developed a system to create and analyze the building envelope. The system helps designers to consider a large number of alternative material and construction systems. Generation of feasible alternatives is performed as a constraint-based search problem, for which components of the building envelop must satisfy performance requirements. Selection and ranking of the alternatives is done after evaluation involving an array of performance criteria as well as priorities supplied by the designer.

Haber and Karshenas (1990) developed a system called CONCEPTUAL, an expert system for structural design with emphasize on the conceptual stage of design. The system places emphasis on establishing cost estimates for different building alternatives. The selection of the structural type is made from a predefined database of components. The rational behind the development of the system is based on the argument that designers base their decisions mostly on experience and intuition. As such, the automated knowledge-based expert system is based on a model of the process by which a human expert arrives at a conceptual design for a building.

Liggett (1990) developed a computerized approach to conceptual design in which methods of algorithmic generation of alternatives and manual construction of layouts by means of a graphical interface are used to solve space allocation problems.

Maher and Fenves (1984) presented HI-RISE, an expert system for the preliminary structural design of high-rise buildings which serves as a designer’s assistant by generating feasible alternative load carrying systems. HI-RISE utilizes both a rule- and frame-based knowledge representation. Frames are used to represent knowledge of structural systems, subsystems and components in a hierarchical manner. Given a fixed three dimensional layout, alternative load carrying systems are generated by a search through the hierarchy of structural subsystems, using heuristic rules to eliminate infeasible systems. Typical design alternatives are rigid frames, cores, tubes, braced frames, etc., with steel or concrete construction. The user can select one of the feasible alternatives for further detailed investigation.

Moore and Miles (1991) developed a user-oriented knowledge based system (KBS) for use in the conceptual design of bridges. Since the conceptual design of bridges is mainly based on heuristics and personal judgement and therefore depends greatly on the experience of the engineer, the KBS uses an interactive knowledge elicitation (KE) process, with the unusual feature of several experts involved to provide the knowledge in the same domain. The KBS is later being verified by the experts involved in the KE process, and by other independent experts and users. The experience gained from the development, implementation and verification of the system was shown to be relevant to the creation of future KBS's, particularly within the engineering environment. In their next attempt, Miles and Moore (1991) examined the use of KBS technology in civil engineering design, with especial reference to bridge design. Based on assessments of the effectiveness of the systems, and on reasons for the slow acceptance rate of KBS's by industry, the current use of heuristics in KBS's was analyzed and a few broad groupings of heuristics were identified. The utility of KBS's was noted to be as valuable design aids in addition to being simulations of expert thought processes. A further study by Moore and Miles (1996) discussed a method for improving the consideration of costs during conceptual design, in which computer-based techniques allow designers to rapidly explore many options to a high level of detail so as to inform them of the cost implications of their decisions. The method is able, at the very early stages of design, to analyze the impact of large and small changes to the artifact. The paper presents a practical application of the method to bridge design.

A further study by Moore et al (1996) developed a knowledge base system for bridge aesthetics for use in the conceptual stage of design. They described the methodology used to obtain the knowledge, which, due to the subjectivity of the domain, involved supplementing knowledge elicitation with questionnaires as a means to check the correctness of the experts' rules. This KBS was suitable for assessing the aesthetics of small to medium size road bridges.

Moore et al (1997) also developed of a decision support tool for the conceptual design of bridges which incorporated a restructured version of a previous knowledge base (KB). This new version allows the system to be altered and extended by system users who are not expert engineers. This is accomplished by using a novel form of KB in which the knowledge is fragmented into separate concepts associated with design solutions. In addition, the system uses a new type of user interface which involves a critiquing style of interaction in which the KB only interacts with the user when it detects either a possible error in the design or a more suitable design solution.

Sham (1991), as part of a much greater research effort in the computational modeling of conceptual design using artificial intelligence techniques, presented an experiment in knowledge elicitation (KE) which encompassed the entire process of extracting, characterizing and crafting design knowledge into an exploitable form, with special reference to bridge design. The merits and shortcomings of the methods used in the experimentation were compared and contrasted, while the problems involved in acquiring knowledge in a multiple expert environment were discussed.

Borkowski et al (1991) investigated conceptual decisions taken during the preliminary design of structures, use of computer support for such decisions and employment of AI-techniques in computer support modules. Several issues such as intelligent access to previous design experience stored in databases, automatic generation and comparison of plausible alternatives, and acquisition of new knowledge through algorithmic structural optimization are discussed. The difficult task of supporting innovative solutions was an important consideration of the work, and several knowledge-based computer programs illustrated the implementation of the proposed ideas.

Reddy et al (1993) discussed the use of informal methods in the optimization of concrete structures at the conceptual design stage, such as heuristic designers' expertise, and at the design realization stage, such as approximate numerical techniques. While discussing the differences in the optimization of steel and concrete structures, they introduced a formal method for the cost optimization of reinforced-concrete structures using a derived cost function for estimating the optimum sizes of members at the conceptual design stage. The corresponding system, with capabilities limited to the design of columns, beams and slabs, was developed for the optimum-cost design of reinforced-concrete members and made use of heuristic knowledge provided by expert designers.

Fuyama et al (1993) attempted to computerize the conceptual design of structural steel buildings. The motivation behind the work was reported to be the positive effect that the conceptual stage of design has on the quality of a building, as well as the then current lack of computer-bases techniques to handle the conceptual design of building structures. In their research, an interactive design system called Building Engineering and Reasoning Tool (BERT) was developed with the capability to design and "optimize" member sizes through reasoning about the behavior of a steel frame structure while different configurations were evaluated by means of a cost estimating scheme that accounted for material, fabrication and erection costs. A further study (1994) elaborated upon BERT, with focus on a discussion of the object-oriented representation and reasoning schemes employed in the implementation of the design system. Another study (1994) presented a more complete version of BERT which incorporated a behavior-based methodology for designing structural members to meet strength and interstory drift demands caused by equivalent static earthquake loads acting on tall moment-resisting steel frame structures. This work attempts to minimize the total weight of the structural system, with due consideration given to both strength and stiffness requirements.

Mathews and Rafiq (1994, 1995) applied genetic algorithm (GA) technology in the development of a decision-support system for conceptual building structural design. They mentioned that pre-processing enables independent sub-systems to be identified, thereby reducing the complexity of the design space. For example, reinforced concrete columns vary in size and reinforcement detail but, for given load ranges, the cost of optimal sections can be determined beforehand. Using such pre-processing, a GA was applied to minimize the cost of the structural grid layout and floor system for a building of given plan dimensions, while at the same time maximizing floor flexibility and usage comfort. However, the study did not consider the design as a multi-criteria optimization problem but, rather, found an optimal design for each criteria separately.

Mathews, Rafiq and Bullock (1996), in a further attempt to develop an algorithm for the conceptual design of buildings, proposed the integration of different objective criteria, such as the reduction of overall cost and the improvement of final-built quality. To make their task easier, they proposed looking at medium-rise office buildings instead of high-rise buildings. The use of a GA as a search tool was recommended and they proposed a specific algorithm which allowed for interaction with the designer. However, the study only achieved a prototype flowchart of such an algorithm.

Arciszewski (1984) dealt with structural shaping, where qualitative parameters and their feasible states are presented in the form of a morphological field. In this research, computer-aided analysis by means of anonhomogeneous Markov chain is proposed for the determination of wind bracing types.

Arciszewski and Ziarko (1991) proposed a new approach to structural parametric optimization. The method employs a two-stage case-based optimization process, including learning and production. The system later was tested for four experiments concerning the design and optimization of rigid steel frames under different loadings. The experiments were performed to determine the feasibility of the proposed optimization. It was concluded that the expected feasibility of the method was achieved.

Arciszewski et al (1994) developed a methodology for applying machine learning to problems of conceptual design, and presented a case study of learning design rules for wind bracing in tall buildings in which design rules are generated by induction from examples of minimum weight designs. This research investigated the suitability of machine learning methods involving constructive induction, which automates the search for problem-relevant attributes beyond those originally provided. The final product is a set of decision rules which specify design configurations that are recommended, typical, infeasible, or those that should be discarded. These learned rules capture some of the expert's essential understanding of the design characteristics involved in selecting wind bracing for tall buildings. The results of the case study were promising and demonstrated the potential practical usefulness of the proposed methodology for the automated generation of design rules.

Another attempt by Arciszewski and Michalski (1994) focused on initial ideas for a design theory based on the inferential theory of learning. The theory employs a process that changes design specifications and background knowledge into the desired design. The paper provides the basic tenets of the theory and proposes a system of design knowledge transmutations. To further elaborate on the theory, individual transmutations are established and explained using examples from the area of the conceptual design of wind bracings in steel skeleton frameworks for tall buildings.

Szczepanik et al (1996) presented the results of a performance comparison study of two symbolic learning programs. One program uses single representation space while the other employs constructive induction. The experiment was conducted on a set of optimal designs of wind bracing in steel structures. The paper concludes that constructive induction offers several benefits when compared to learning based on the use of single representation space.

Arciszewski et al (1999) once more presented the basic concepts of inventive design, as applied to structural engineering. The paper discusses the importance of the ability to produce an inventive design in a short time. This study employees genetic algorithms to generate best concept designs in the structural engineering field, with focus on steel frames and outriggers.

Grierson (1994) proposed a computational model for the conceptual design of simple bridges and buildings through the integration of a genetic algorithm (GA) and an artificial neural network (ANN). Later studies (1996, 1997) extended the work to the conceptual design of building structural systems in general. Self-organizing solution paradigms (GA+ANN) were used to develop a computing system that optimized the conceptual design process. Specifically, a preliminary computational model for conceptual design was presented that employs a genetic algorithm in tandem with a neural network to generate best-concept design solutions using directed random search guided by artificial learning. A neural network is used to establish the fitness of each conceptual design. The computational model is illustrated for the routine conceptual design of bridge and building structural systems.

Kunighalli and Russell (1995) provided a framework for the development of Computer-Aided-Design/Computer-Aided-Construction (CAD/CAC) systems which contain software tools related to conceptual design, structural and foundation analysis, design of structural components, routine mathematical and optimization functions, construction management, Computer Aided Process Planning (CAPP), process simulation, and constructability analysis. The research highlights work in domains related to CAD/CAC and investigates the enhanced efficiency and effectiveness of the proposed systems for the design and construction of civil engineering structures.

Chierdhast and Ambo (1995) discussed a practical approach for solving topology optimization problems for planar cross-sections, which involved a rigorous method for the conceptual design of structural components. A standard nonlinear programming algorithm involving continuous-valued design variables is used to solve the optimization problem.

Shiva Kumar et al (1995) presented a knowledge-based system for the design of concrete bridges with emphasis on the initial modeling of the problem, which is an important step in KBS development. KBS's for bridge design have been traditionally implemented as simple production rule systems. However, since a thorough examination of the application domain and identification of the required artificial intelligence techniques are necessary for full KBS development, this research argues that an integration of AI-based problem-solving techniques is necessary to address the various tasks of bridge design. Furthermore, it argues that a design process model based on rule-based inference, synthesis and critical evaluation techniques is required to address the knowledge-intensive tasks of site selection, bridge layout planning, conceptual design and preliminary design of concrete road bridges, in an efficient manner.

In a work that applied a GA to conceptual design, Hudson and Parmee (1995) summarized methodologies for a grammar-based chromosome system. The study pointed out that when applying a GA to a conceptual design problem that neither the structure of the final solution nor the design space to be searched should be fixed, that the evaluation of concepts does not involve simple qualitative or quantitative comparison, and that a range of good solutions is more important than a single solution. The stated goal of the work was to develop practical systems for the qualitative, rather than quantitative, solution of realistic conceptual design problems.

In a recent study, Beck and Parmee (1998) focus on the conceptual design of a building and attempt to design such as to minimize both project cost and heat loss and maximize both heat gain and occupant comfort. A fine-grained GA technique was employed. This study, however, did not include account for alternative structural layouts.

Fruchter et al (1996) presented an interdisciplinary communication medium for collaborative conceptual building design which involved intensive cross-disciplinary communication of design concepts and decisions. The requierment to overcome extensive delays, miscommunication and confusion caused by difficulty in producing and expressing information, which often have a negative impact upon the time required to achieve design consensus and on the quality of the final design, triggers the need for a framework for interdisciplinary communication to support collaborative conceptual design. Since then-current computer tools provided little support for the special needs of representation and reasoning posed by cross-disciplinary communication in collaborative conceptual building design, this study proposed a method for interdisciplinary communication. The method enabled designers to propose a shared model, interpret the model for various disciplines, critique the discipline models to derive behaviour and compare it to function, and explain the results to other members of the team. Such a propose-interpret-critique-explain paradigm as a communication cycle for collaborative conceptual building design is presented as an experimental software prototype that integrates graphic representations and AI reasoning for evolving building design concepts and uses a graphic environment as the central interface to reasoning tools that support the collaborative design process. In a second study (1996), Fruchter elaborated on collaborative conceptual building design using the previously developed system to integrate a shared graphic modeling environment together with network-based services to accommodate the many perspectives of an architecture/engineering/construction team.

Jo and Gero (1996) employed a GA for space layout planning. In the study they optimize the distribution of available space among different activities in a building in order to minimize the cost of taxiing between those activities. They concluded that a GA is able to generate good designs for complex design problems.

Wang and Gero (1997) discussed the application of machine learning techniques in a knowledge support system for the conceptual design of bridges. A sequence-based prediction method is used in which the most recent numbers of similar design cases are used in predicting the characteristics of the next design, and more recent cases are given stronger influence on decision making in the new design situation than older cases. This research developed a prototype of a sequence-based prediction tool and carried out a number of experiments comparing results with those for other methods and concluded that the method has potential for success in engineering design.

Chinowsky (1996) introduced an cooperative conceptual design environment that supports interdisciplinary design teams with enhanced information access and object manipulation capabilities. This research demonstrates the need for such s system through arguing that, while computers provide significant assistance in the storage of project documents and the creation of detailed drawings, pivotal economic and quality enhancement benefits are generally lost during the conceptual design stage, and that such benefits have great opportunity to economically, aesthetically and qualitatively impact final design solutions.

Park and Grierson (1997) developed an algorithm for the optimal conceptual design of medium-rise buildings accounting for the cost of the structure and the quality of occupant space. The approach generates best-concept designs by simultaneously optimizing two conflicting criteria concerning the project cost and the flexibility of floor space usage. Specifically, Pareto optimal equal-rank designs that are not dominated in both criteria by any other feasible design are found using a multi-criteria genetic algorithm. The MGA process resembles that of a simple GA (Goldberg 1987), except that the fitness evaluation of candidate designs is based on a distance metric related to the Pareto-optimal set. The study considered only one type of structural system and assumed that the building is supported laterally by means other than the structural frame. They found that there is a performance trade-off between the objective criteria and that it is up to the designer to make some compromises to arrive at an acceptable design.

Ravi (1997), in an attempt to create a knowledge-based system for the integrated design of multistory office buildings at the preliminary stage, developed an interactive program which poses questions to the designer as it generates a desirable design. However, while being user-friendly and able to generate promising results, the system requires a designer with broad knowledge of the different aspects of the design in order to be successfully applied. A further limitation of this system is the lack of inclusion of heating, ventilation and air conditioning (HVAC) considerations in the design procedure.

Shrestha and Ghaboussi (1998) discussed a methodology for the evolution of optimum structural shapes in which a genetic algorithm is used to evolve optimum shape designs that are free to assume any geometry and topology and do not necessarily resemble any conventional design. The approach has the potential to generate new and innovative designs, especially when more complex design problems are attempted. The methodology addresses configurational and topological aspects of the design, and considers discrete member sizes and multiple loading cases for planar and space structures.

Shea and Cagan (1999) used shape annealing techniques as the basis of a computational method for structural configuration design that supports structural designers with varying design intent. The work involved studying roof truss designs conceived by architects and engineers as well as those generated using shape annealing, with the purpose of evaluating the capabilities of shape annealing techniques to meet the varying needs of designers and, as well, to generate spatially intriguing and functional structures at the conceptual design stage. The study concluded that shape annealing generates alternatives that appeal to designers while providing insight into relations between structural form and function.

1.5 OBJECTIVES AND SCOPE OF RESEARCH

As presented in the foregoing literature review, most studies to date concerning the conceptual design of buildings have been limited to but a few aspects of a building project. This research proposes to achieve optimal conceptual designs of high-rise buildings while accounting for all major aspects and conflicting cost-revenue objective criteria. The study will not address the spatial arrangements of functional zones within areas, but will take into account the efficiency of architectural and structural layouts and mechanical and electrical systems.

The primary objective of the research is to develop a computer-based technique for the optimal conceptual design of high-rise buildings, while accounting for competing objective criteria related to capital cost, operating cost and income revenue. Self-organizing computing methods (e.g., genetic algorithms) are employed as the computational basis for modeling the unstructured and evolving nature of the conceptual design process. In particular, a genetic algorithm is used to develop a computational capability to exhaustively explore design domains and evaluate possible design scenarios. A multi-objective approach is taken whereby optimization techniques are employed to establish Pareto-optimal curves/surfaces representing the trade-offs between the three competing cost-revenue objectives for a design. The trade-off relationships between the design objectives provide clear guidelines for the selection of structure type, configuration, layout, materials, windows and elevators (i.e., general of the design concept). Importantly, this trade-off information permits designers to study the gains and losses incurred when selecting one design concept over another, which consequently provides the ability to know the approximate effect of design decisions on the capital cost, operating cost and income revenue for high-rise buildings.

The achievements of the research are summarized as follows:

I. Account for three important and conflicting objective criteria related to capital cost, operating cost and income revenue for the global optimal conceptual design of high-rise office buildings.

II. Development of evaluation functions for the cost-revenue objective criteria.

III. Account for a wide variety of architectural space layouts.

IV. Account for different gravity and lateral load structural systems.

V. Development of a set of rational design constraints for buildings conceptual design.

VI. Development of a practical computer-based design tool for the optimal conceptual design of high-rise office buildings.

VII. Capability to create Pareto trade-off curves/surfaces to facilitate designers in their task to choose good compromise designs for high-rise buildings.

VIII. Capability to estimate the potential profitability of building designs over time.

1.6 ASSUMPTIONS AND IDEALIZATIONS

The assumptions and idealizations adopted in this study for the conceptual design of high-rise office buildings are as follows:

1. Mean's manuals are used to estimate the cost of construction (R.S. Means 1999).
2. Beams and slabs span over columns to form floor systems.
3. Columns are arranged in lines in two orthogonal directions.
4. Structural grid lines defining bay sizes are regularly spaced.
5. Only one type of floor layout prevails over all stories of the structure.
6. Only static or equivalent static environmental loads, as permitted by building codes, are considered. Dead loads are assumed to be invariant with changes in member sizes.
7. The material behaviour of steel and concrete is assumed to be linear elastic, and second-order geometric nonlinear (P-Δ) effects are not considered.
8. All structural members are taken to be prismatic and straight.
9. Connections between members are assumed to be either fully fixed or simply pinned. Member lengths are measured using centre to centre dimensions.
10. It is assumed that the floor area occupied by columns is negligible.
11. In lieu of exact analysis, the portal method of approximate analysis (Hibbeler 1997) that locates the points of flexural inflections at mid spans of members is used to estimate forces in beams and columns of systems relying on the beam-column connections to carry the lateral loads. (The cantilever method of approximate analysis is more accurate than the portal method for slender buildings. However,

the latter method is computationally less expensive and, through a separate study, was found to produce comparable results to the cantilever method for the building considered by this study). In structural systems carrying lateral loads by means other than the framing action of beams and columns, such as bracings and shear walls, the forces induced in these stabilizing elements are found through determinant modeling and analysis (e.g., a shear wall acts as a cantilevered column). Member sizing is performed based on the worst-case combination of internal forces induced in members due to dead (D), live (L) and wind loads (W), as follows:

a) 1.25 D+ 1.5 L

b) 1.25D + 1.5 W

c) 1.25D + 0.70 (1.5 L + 1.5 W)

12. The distribution of lateral loads between different lateral load resisting systems is as explained in Chapter 2.
13. It is assumed that windows are installed one meter above floor level (task level) and stretch to the ceiling.
14. For calculation of energy gain or loss, it is assumed that minimum and maximum temperatures occur in January and July, respectively.
15. The building mass is considered to have no impact on HVAC energy consumption (Canadian Institute of Steel Construction & Canadian Steel Construction Council).
16. The building working hours are assumed to start at 8 am and end at 6pm.
17. It is assumed that the artificial lighting system and office equipment are fully functioning during working hours and only half operating during off-work hours.

18. The ventilation system is assumed to be working at full power in working hours and at half power at other times.
19. It is assumed that the HVAC system only employs gas boilers and electrical chillers.
20. It is assumed that designs having larger spans, more window area and bigger floor area that benefits from natural day light are more likely to generate higher revenue income.

1.7 THESIS OUTLINE

Presented in Chapter 1 are an overview of the conceptual design of high-rise building, a literature review of the state of previous work concerning computerized tools for the conceptual design of engineered structures, and an outline of the study.

Presented and discusses in Chapter 2 are the major structural, mechanical and electrical systems involved in the design of high-rise buildings and their suitability for different building scenarios. The chapter is concluded by identifying the parameters and variables adopted by the study as the basis of the computer-based method for conceptual design of high-rise buildings that is developed and applied in Chapters 3 and 4.

Developed in Chapter 3 is the computer-based conceptual design method for office buildings, based on Pareto optimization using a multi-criteria genetic algorithm. A major portion of the chapter is devoted to describing the means by which the capital cost, operating cost and revenue income are evaluated for a building design. The chapter is concluded by a detailed description of the conceptual design procedure.

Presented in Chapter 4 are four design examples to illustrate the effectiveness, efficiency and practicability of the developed computerized tool for the conceptual design of high-rise office buildings. Results are presented in colour graphics that identify the trade-off relationships between cost and revenue for office buildings.

Summarized in Chapter 5 are the conclusions resulting from the study and directions for future research.