CASE STUDY FOR IDENTIFICATION AND EVALUATION OF CONSTRUCTION INNOVATIONS: THE HOTEL GEORGIA PROJECT

by

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ABSTRACT

Architectural, Engineering and Construction (AEC) projects are becoming more complex in terms of client requirements, stakeholder issues, physical, budget and time constraints, and safety and environmental concerns. These constraints have spawned ad-hoc innovations in some AEC projects, without structured frameworks for their assessment, resulting in varying success for these innovations.

The primary goal of the thesis is to test an existing framework for evaluating innovative design and construction technologies for high-rise buildings by way of a case-study. The case study is a 48-story structure (with an 8-level sub-grade parkade) in a downtown setting with significant constraints and challenges. Unlike most other assessment frameworks which are single-issue based (financial, cost, time or risk), a holistic method that captures a broad range of critical issues at the micro and macro levels is used to screen a number of construction innovations. The process highlights the primary difficulty in balancing stakeholder issues, technical/engineering requirements and project goals in assessing the overall feasibility and net benefits of an innovation. As a useful tool, it facilitates the engineering/technical judgment of proposed innovations and provides evidence of a sufficient trade-off between incremental 'cost and benefits' to justify a detailed evaluation and possible subsequent use of a subset of the innovations that passed successfully through a tiered first stage evaluation process.

A secondary objective is to propose appropriate quantitative models for a detailed evaluation of the screened technologies that not only seeks to quantify incremental cost and benefits (e.g. time, increased revenue, etc.) but also assess the level of certainty (in benefits and cost) of innovative construction technologies. An illustrative evaluation provides insights as to the level of modeling and analysis required to evaluate an innovative or novel strategy both at the 'activity/ work package' and project levels. The quantum of data required at the pre-construction planning stage coupled with the lack of easy to apply evaluation models probably accounts for the non-prevalence of detailed quantitative evaluation of innovative construction technologies on AEC projects, especially in terms of impact at the project level and the degree of certainty with which net benefits are likely to be achieved.

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CO-AUTHORSHIP STATEMENT

The author of this thesis was responsible for the writing of the manuscript. He performed the analysis and critical interpretation of information, which included a review of literature, acquisition of data and consultation with industry professionals.

The co-author: Dr. Alan Russell - Professor, Department of Civil Engineering, and Chair, Computer Integrated Design and Construction - UBC, participated in the development and drafting of ideas and was an equal partner with the thesis author in the review and revision of the manuscripts.

Date (2007/10/20)

Signature of Research Supervisor ______________________ ____________

Signature of Thesis Author ______________________ ____________

CHAPTER 1[1]

1.1 Introduction

The Construction Industry has long been criticized for its 'lackluster' pursuit and adoption of innovation as compared to other industries (Bernstein & Lemer, 1996; Skibniewski & Chao, 1992; Tatum, 1984). The result is comparatively low productivity, project time delays, cost-overruns and substandard quality all of which contribute to less value for money. (Laborde & Sanvido, 1994) indicate that the construction industry is sacrificing enormous benefits in terms of profit, productivity, cost-effectiveness, quality product and international competition due to the neglect of construction process innovation.

The uncertainties involved in the use of new technologies have left many construction businesses undecided between conventional and innovative technologies. For those instances where innovative methods have been introduced, decisions have been made on an ad-hoc basis with varying success (Chang et al., 1988; Napier et al., 1988, Lutz et al. 1990). Project professionals and stakeholders arrive at such decisions using established practice, organizational (and historical) knowledge and experience. The need for a structured framework in evaluating innovative technologies for Architectural Engineering and Construction (AEC) projects cannot be overemphasized. The need for successful project implementation requires that decisions on selection of technology be based on an objective understanding and evaluation of all relevant factors and implications. The use of a formalized approach eliminates or minimizes bias and individual influences in the evaluation of innovative technologies and considers the influences in all aspects of the project (including life cycle issues). Most works in this respect have either been quite theoretical or of little relevance to the unique conditions (non-repetitive/dissimilarity designs, changing project players and technology etc.) of AEC projects.

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[1]A version of this chapter is being prepared for CSCE 2008 International Construction Conference. Whizz, A.D. Russell; R.C. Awuni and S.F. AboMoslim (2008)

A major challenge in evaluation schemes for innovative technologies is how to forecast the benefits associated with them at the front end of the planning process. Appropriate evaluation tools should broaden the 'judgment spectrum' beyond the conventional factors of time, cost and quality if a holistic assessment is to be made (Russell et al. 2006).

It is essential to consider unquantifiable benefits such as technical solutions to design and physical constraints, solutions to congestion, safety, environmental impact, reputation and competitive advantage and risk mitigation at the preliminary stages of an evaluation (screening) framework.

This thesis seeks to contribute to the development of an analytical framework for the evaluation of innovative technologies in the AEC industry. In addition, it seeks to demonstrate the challenge involved in identifying technologies relevant to a specific project context and their evaluation and properties required of an evaluation framework that is responsive to the practicalities of the construction industry. A detailed case study is used to help identify some of the features required and considerations involved in evaluating the suitability of an innovation. The framework introduced can serve as a platform to generate useful ideas, discussion and critical analysis pertaining to the selection and assessment of innovative technologies and construction strategies, referred to hereinafter simply as innovation.

1.2 Definition of Innovation

The term 'innovation' has been used variously to describe new, different and significant products, inventions, technologies, processes, concepts and practices. (Freeman & Soete, 1997) defined innovation as "actual use of non-trivial change in a process, product or system that is novel to the institution developing the change." It has also been described as an appreciable improvement in a process or product as a result of adopting (or adapting) an administrative or a technical concept by an organization (Laborde & Sanvido, 1994; Rogers, 1983; Slaughter, 2000). (Sexton & Barrett, 2003) emphasized that the concept or idea (administrative or technical) which is the starting point of innovation, need not be new to the 'world', just new to the adopting organization. By the term 'innovation' we intend to draw a clear distinction between the 'novel uses' of existing technologies as against a 'novelty'.

The term innovative construction technology is used in the context of the direct or adaptive use of known or existing methods, hitherto not used within the project environment or by the project stakeholders. While the novel use of some technologies or methods in a project can produce gains in terms of project objectives and outcome, there is always the element of uncertainty with respect to the outcomes and hence careful evaluation is worthwhile.

From the above definitions, 'Construction Process Innovation' can be described as a nontrivial improvement in construction methods applied to construction operations for effective results or incremental benefits (Laborde & Sanvido, 1994; Rogers, 1983; Slaughter, 2000)

Another definition deals with 'Construction Strategies', which are the plans (detailed or cursory and technical or managerial) for achieving success in construction projects as measured by one or more of time, cost, quality, client satisfaction, etc. An innovation may constitute a component of (or support) a strategy. For instance, the overall approach for deep basement excavation for a small floor plate in a restricted site in a timely, efficient and safe manner (considering the limitations of conventional methods) is largely one of strategy. However, a proposal to use a free standing construction platform with a clamshell in combination with other excavation and materials handling methods is an example of innovation.

1.3 Motivation

The increasing complexity of projects coupled with the heightened demand for performance (including shorter schedules) requires innovation in project-delivery systems (Russell et al., 2006). Shorter design and pre-construction planning periods militate against comprehensive analysis of construction techniques. Therefore, construction technologies are often determined at the construction stage without having evaluated their full impact (costs or benefits), resulting in the continued use of known and conventional technologies. However, failure to use value-adding innovations may preclude the timely realization of overall project objectives. The uniqueness of AEC projects makes it difficult to develop a comprehensive framework that can help project practitioners and constructors identify innovative technologies and methods, and then perform a holistic evaluation of them.

1.4 Thesis Objectives

Thesis research objectives include:

(i) To conduct an extended case study of a complex high-rise building in a downtown setting to explore issues related to characterizing a project's context, identifying relevant technologies and strategies for evaluation, and representing the dimensions of a technology in support of a thorough evaluation to determine feasibility, benefits and risks. The case study project has considerable technical complexity and is located in a congested urban environment which provides enormous constraints and challenges. These combined with client time and cost objectives provide a real need for the introduction of innovative construction method and technologies; and,

(ii) To contribute to the development / refinement of an existing preliminary assessment (screening) framework, proposed by (AboMoslim & Russell, 2005) and suggest modeling needs for the quantitative evaluation of promising (screened) technologies.

In keeping with the thesis objectives, the following topics are highlighted in the thesis:

i) The importance of creating incremental value through the identification, assessment and adoption of construction process innovation;

ii) The importance of knowledge management and tracking innovation on a world wide basis;

iii) The benefits of a framework / structured approach for assessing innovation to AEC projects and the construction firm;

iv) Prior work on evaluation tools, methods and frameworks for evaluating innovative construction technologies;

v) Contributions to the development of a two-tier framework for the technical, economic, risk, stakeholder and environmental evaluation of new technologies; and,

vi) Application of the framework through the evaluation of a number of innovative construction methods to the case study project. The case study highlights the risks, benefits and challenges involved in introducing new technologies to AEC projects.

1.5 Methodology

The methodology used in preparing the thesis includes the following;

i) An extensive literature review in innovation (theory, practice and evaluation) from the academic literature, industry and trade journals;

ii) An extensive investigation for innovative technologies, applicable to the case study.

iii) Review of site and architectural/engineering designs to assess the physical and technical conditions and to determine how they enhance or inhibit the use of identified innovative methods.

iv) Meetings, interviews and presentations to members of the project's 'Construction Manager', the Scott Construction Group, Vancouver, B.C. The views/input of other stakeholders (designers, regulators, sub-trades etc.) was obtained through the Construction Manager, in the form of feedback on the innovative proposals.

1.6 Thesis Structure

The thesis is structured in three-parts. Chapter 2 discusses a brief literature review of the current state-of-the-art in identification and evaluation of construction innovations. Chapter 3 examines the details of the case study, expands the features of an existing evaluation framework and applies it to the case study. Chapter 4 briefly outlines the procedure and features for a detailed evaluation and its application to a number of technologies. Chapter 5 presents conclusions and suggestions for future work.

CHAPTER 2[2]

In what follows is a discussion on issues of knowledge management, the importance of a structured framework for identifying and assessing innovations, and a review of the literature to identify useful assessment criteria for the development of evaluation frameworks for innovative technologies.

2.1 Importance of Tracking Innovation on an International Basis

Increasing domestic and international competition (Bernstein & Lemer, 1996; Tatum, 1986; Uwakweh, 1991) has motivated construction and engineering firms to engage in the search for innovative ways to remain competitive on the global and local scene. Yet most construction and engineering businesses in North America (U.S and Canada) do not readily develop and implement project based innovative construction processes as compared to Japan (Bernstein & Lemer, 1996; Gerwick Jr., 1990). The result is that these businesses do not adopt a formalized approach to identify, evaluate and introduce innovative construction technologies and processes (Chang et al., 1988).

Tracking innovations on an international basis enables project organizations to update their operations, improve productivity and reduce costs (Madewell, 1986; Tatum, 1989). Other benefits that accrue to the firm include an improved knowledge base, greater technological competitiveness, enhanced reputation and a more realistic appraisal of the risks associated with innovation. Making project stakeholders appreciate that the benefits of identifying, assessing and adopting innovative technologies involve more than just the bottom line of profitability is an issue of knowledge management. Improving the pace of innovation in the Architectural Engineering and Construction (AEC) Industry requires a structured approach to identifying, assessing and adopting/adapting innovative technologies. That cannot be achieved without effective and efficient knowledge management systems in project organizations.

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[2]A version of this chapter is being prepared for CSCE 2008 International Construction Conference. Whizz, A.D. Russell; R.C. Awuni and S.F. AboMoslim (2008).

As stressed by (Tatum, 1984) information and knowledge management are vital to the construction process and forms a major link in the broad framework of construction technology.

The Construction Industry Cost Effectiveness Project (CICE) identified the lack of industry-wide information as one of the major impediments to implementing new technologies (Business Roundtable - Construction Industry Cost Effectiveness Reports & White Papers, 1982).

2.2 Knowledge Management and Innovation Assessment

In the evaluation and implementation of innovative construction technologies, researchers and project professionals have used various information and knowledge management decision support tools. (Chang et al., 1988) adopted an extensive and elaborate procedure of relevant library search, pilot interviews with experts, contacts with code and building organizations, the U.S. patent and trademark offices and testing organizations. (Ioannou & Leu, 1991) recognized the peculiar characteristics of technology information and the need for knowledge management to deal with the proliferation of construction technologies. Subsequently, (Ioannou & Liu, 1993) developed a computer based system to identify, compile and facilitate the knowledge management of emerging construction technologies. (Udaipurwala & Russell, 2002) described a computer assisted system that sought to integrate construction methods and knowledge management as an adjunct to the construction planning process. (Kangari & Miyatake, 1997) identified a firm's capability of effective, valuable and timely information gathering as a very important factor for the development and use of innovative construction technologies in Japan. Development of such a capability requires an elaborate knowledge based system that treats various levels of management in a construction firm, in order to facilitate the capture of both internal and external knowledge about innovative construction methods.

In relation to the need to keep abreast of developments on a world wide basis, the most relevant question was posed by (AboMoslim & Russell, 2005), *"how do firms gather and manage knowledge pertaining to new concepts and technologies (for design and construction) in terms of materials, equipment, methods, information process and procurement systems?"*

The distinctiveness of construction operations, projects and project based businesses requires a unique approach to the process of innovation assessment, different from other industries (AbouRizk et al., 1994; Tatum, 1987). In the manufacturing and process industries, product and process innovation assessment and adoption are carried out with the view of long term application and the benefit of repetition. In contrast, a construction project is 'short lived' without the benefit of repetition and requires a completely different approach to innovation.

Technology in various forms accounts for a substantial portion of the cost of construction, and yet its selection and adoption for most projects is ad-hoc and without formalized assessment (Lutz et al., 1990). What is needed is a thorough and analytical evaluation and review process, but in a manner which reflects the realities of the industry in terms of information and resource availability. Tingling and Parent (2004) indicate that the adequate appreciation of benefits, costs and risks associated with innovative processes is essential to their evaluation. (Kangari & Miyatake, 1997) suggest that developing an effective technology evaluation procedure ensures the selection of innovative technologies with the maximum positive results on project and organizational objectives. A carefully crafted assessment framework therefore serves as a basis for developing a decision support system for identifying, evaluating and selecting innovative construction processes. By employing objective criteria, realistic comparisons can be made between alternatives.

2.3 Assessing Innovative Construction Processes for Buildings

Researchers have proposed various schemes in evaluating building technology, including sustainable technologies (Chang et al., 1988; Ioannou & Carr, 1988; Laborde & Sanvido, 1994; Nelms et al. 2007; Nelms et al. 2005). Most of these works are not directly linked to the construction process nor do they offer a comprehensive assessment or methodology for innovative processes in the construction industry.

The objective of our work is an extension of existing analytical tools for the assessment and selection of appropriate or innovative construction technologies and methods.

While the methods or technologies analyzed may not always be a perfect fit for all projects, the framework employed in this study can serve as a useful basis for decision making about the use of specific construction methods.

To date, researchers have adopted various methods to evaluate construction technologies. (Chang et al., 1988) proposed an evaluation scheme to identify technologies with the highest potential benefit to a building program.
The scheme serves as a preliminary screening to determine innovative technologies that have maximum benefit to any particular construction program (or project) in terms of an impact factor based on the 'quantum' of the technology that would be used in the program or project. The impact factor served as basis to identify potential technologies for further investigation, using cost-benefit, risk and technical feasibility. The method is a useful generic framework but its application is limited to long-term programs with significant repetition. However, the construction industry is dominated by 'fast-paced-one-off' projects which do not enjoy the benefit of repetition.

A further development in the generic quantitative assessment for alternative technologies was proposed by (AbouRizk et al., 1994) and applied to microtunneling for sewer replacement with the open-cut technique as the base case (or conventional method). It involves an evaluation of alternative technologies based on planned project objectives, assessment criteria and associated risk factors. (Chao & Skibniewski, 1998) developed a fuzzy logic approach that considers the risk of adopting alternative technologies.

(Foliente et al. 1998) proposed a performance- based assessment of construction technologies. This approach was emphasized by (Becker, 2002), who used a performance based methodology to evaluate and categorize the faults and deficiencies in innovative technologies for buildings. He concluded that building regulations, codes and standards are mostly based on conventional or traditional building systems and are not reflective of emerging innovative technologies.
The traditional method of economic evaluation can be a useful basis of evaluation as emphasized by (Russell & Arlani, 1981), in generating net present values for life cycle costing of alternative technologies.

Evaluating the technologies based on their performance facilitates a determination of the limitations and risks associated with innovative construction methods and their related solutions. Further to this, (Lutz et al., 1990) proposed a comprehensive evaluation and decision framework based on a three stage quantitative analysis of the technical, economic and risk dimensions of innovative technologies. Technical, savings and risk assessment factors were developed as the basis for an overall assessment factor which is a measure of the potential utility of a particular technology. A decision aid in the form of a 'Technology Index' (T. I.) was further derived as an expression of the 'expected utility' of the evaluated technology relative to an existing or comparable technology. Most of the evaluation methods reviewed in the literature do not consider the introduction of multiple innovations in a project setting and their interactions. This is particularly important to our case study project which is challenged has a number of challenges that cannot be addressed by the use of a single innovation. However, the approaches of (Foliente et al., 1998; Lutz et al., 1990) considered the interaction of building systems, technologies and construction methods in their evaluation schemes.

(AboMoslim & Russell, 2005) developed an elaborate framework for screening innovative design and construction technologies. The framework treats an extensive range of factors and sub-factors (with their descriptors or values) as filters for the preliminary assessment of a number of innovative technologies for high rise buildings on a world wide basis. The work reviewed in the literature coupled with experience gained from applying it to the case study serves as a platform for refinement and extension of their framework to facilitate the assessment of the implications and relative benefits of innovative construction technologies from a 'global project view'.

2.4 Evaluation Criteria for Innovative Technologies

Identifying the critical factors for assessing innovative technologies is a key step towards the successful selection and implementation of innovations in construction projects. Researchers have suggested various criteria in assessing innovative construction methods. Many can be described as theoretical in context (AbouRizk et al., 1994; Ioannou & Carr, 1988; Skibniewski & Chao, 1992), others have practical application (Chang et al., 1988; Lutz et al., 1990).

A brief literature review of innovation was undertaken in order to identify generic factors or criteria useful in assessing innovative technologies within the specific project context.

The limitations of using the traditional tools of Return on Investment (ROI) and Net Present Value (NPV) to measure, quantify and represent cost, time and risk of innovative technologies have been observed by a number of researchers (Skibniewski & Chao, 1992). These limitations are most acute for the 'short-lived', one-off construction project with varied players and interest and with little opportunity to have repeated uses of the innovation on future projects.
(Laborde & Sanvido, 1994) proposed an elaborate process using cost/benefit criteria for evaluation of innovative technology based on project needs, cost of technology, payback period, time to implement, impact on project, compatibility and safety. (Proverbs et al., 1996) presented factors for evaluating innovative methods of concrete transportation and placing as plant, equipment & labor availability, building form and location, company practice, work quantity, costs, safety, specification and production rates. (AbouRizk et al., 1994) adopted various risk categories (physical, capability, economic and political) as the main criteria in evaluating alternative technologies. (Chao & Skibniewski, 1998) emphasized the need to address the inherent risk of introducing new technologies as a basis of evaluation. (Chang et al., 1988), in proposing a preliminary screening procedure for building technologies, adopted 'Impact', 'Cost-Benefit Rating' and 'Risk' as quantitative and qualitative criteria. Recommendations for further evaluations are then made based on the technology's performance on the stated criteria.

(Lutz et al., 1990) in an extension to the work of (Chang et al., 1988) proposed a list of technical attributes and sub-attributes of the construction technologies for the 'second-tier' technical assessment. These include: structural serviceability, fire safety, habitability, durability, maintainability, and architectural function. (Skibniewski & Chao, 1992) further emphasized the need to address the inherent risk of introducing new technologies as a basis of evaluation. Risk was described in terms of safety problems, operating risk, system reliability and flexibility.
(AboMoslim & Russell, 2005) identified a number of screening criteria as part of an overall evaluation process to include: stakeholder acceptance, engineering/production/construction/logistics factors, quality, time, cost, and risk.

From the foregoing discussion the following observations can be made of the methodologies and criteria, adopted by other researchers for assessing innovations in construction:

- There is no single generic evaluation framework to assess innovations in the AEC industry because of the diversity of project types and innovation perspectives (construction process, material/component, structural/technical etc.).

- It was further realized that most of the assessment factors considered by other researchers are limited to a single innovation at a particular time, often without consideration of a specific project context. Thus, some of these factors are not useful for projects that are challenged by complex constraints and/or require the simultaneous consideration of several innovations.

The preceding discussion guides the refinement of the framework of (AboMoslim & Russell, 2005) in terms of a revision of the criteria to be treated in the preliminary screening framework that suits a construction process innovation.

CHAPTER 3[3]

3.1 Description of Case Study - Hotel Georgia Project.

The Hotel Georgia Project is a mixed use development (retail, office, hotel and residential) consisting of the renovation of a 1920's mid rise structure and a new high rise tower (Appendix A). The existing structure is a 150 by 120 feet 'L' shaped, 12 storey classical (Gregorian) architecture attached to a 5 storey low-rise, with a basement. The existing structure is designated a heritage building (including certain portions of the interior) by the Heritage Commission of the City of Vancouver. To the North of the 'old' Hotel Georgia is a proposed 48 storey tower (with a relatively small floor plate – 100 ft by 120 ft) with an 8 level basement parkade (Appendix A).

The renovation works involves demolishing the low rise structure so that an adjoining 8 level basement parkade can be constructed adjacent to and under the new tower. The mid rise portion of the existing hotel will undergo extensive internal remodeling and restoration and a seismic upgrade, while maintaining most of its external façade. A number of location, access, contractual and physical constraints pose real challenges for the project, necessitating identification and evaluation of a number of alternative construction methods, including innovative ones.

The project is located in the busy part of downtown Vancouver, bounded on the south and east by Georgia and Howe streets, respectively. The vicinity of the project is marked by heavy pedestrian and vehicular traffic and contains prominent businesses, offices and commercial development. The site can be accessed by either a narrow lane open to adjacent properties (public) or Howe Street (Appendix A). The location poses substantial problems of delivery of materials and logistics to and off the site.

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[3]A version of this chapter is being prepared for CSCE 2008 International Construction Conference. Whizz, A.D. Russell; R.C. Awuni and S.F. AboMoslim (2008).

The project is abutted to the north by the Metropolitan Hotel. On the eastside across Howe Street is the Four Seasons Hotel and on the west side, across a 6 meter lane is the HSBC Tower (Appendix A). All these structures are considerably lower in height than the new tower with basement (below grade) facilities.

The surrounding underground structures pose constraints on the type and methods of shoring, underpinning and settlement control that can be used for the project. Further limitations on subterranean rights, from adjoining properties affects the proposed geothermal system and ultimately the time and cost of its installation. In addition, limitations of air rights over the adjacent buildings put a strain on the methods of material movements for the tower construction. There is no convenient site storage space that can match the scale and speed of construction required. The roof of the existing hotel does not have sufficient structural capacity to act as a storage area. The interior of the hotel is compartmentalized and not suitable for a fast storage and retrieval of construction materials. All of the foregoing site limitations call for the use of innovative construction processes that can enhance materials delivery, storage and handling.

Further complicating the construction process is the need to install a geothermal heating and cooling system at the lowest level of the parkade. The system requires drilling of 500 foot deep holes. Drilling conventionally requires high clearance drilling equipment, making it a critical activity with considerable impact on the schedule of the project. Postponing drilling and later using specially designed drilling equipment removes this activity from the critical path, but at additional cost. The tower is designed with varying floor patterns and features; spiraling floors (P7 to P1), regular commercial floors (2 to 11) and 'slanting' floors from (12 to 48). These changing floor features and sizes have a considerable effect on forming techniques, floor cycle design and duration, and the overall schedule of the project.

Also of note is that the exterior façade and selected interior fixtures of the existing structure (Hotel Georgia) have been designated for heritage protection by the Vancouver Heritage Commission. The commission requires a detailed restoration of the 'Spanish Ballroom',

In addition, extensive repairs/conservation work and rehabilitation/restoration of the hotel's classical architectural features is required.
Careful planning, regulatory oversight and attention to detail are required during the entire renovation and restoration process, all within limited timelines.

3.2 Identifying Relevant Technologies and Strategies

A team of three graduate students in construction management, constituting the 'Student Group' and lead by the authors sought to identify applicable innovative technologies. The size of the group was later enlarged when it became necessary to further investigate aspects of the project related to geotechnical issues and the use of mining technologies.

The authors lead the group in studying the various aspects of the project design, requirements and physical location in order to ensure that innovative strategies identified were suitable for the project context. An initial briefing by the President (and Chief Operating Officer) and the Manager of Technical Services both of Scott Construction Group (Construction Managers of the project) gave additional insight in to the challenges and constraints in the project. The major aspects of the project for which innovations are sought were identified as follows:

- Substructure; consisting of up/down construction, shoring systems, underpinning, excavation strategy, geothermal system installation; and,
- Superstructure; materials handling, lifting, structural and modular technologies, floor cycle times and geothermal technologies.

A detailed 'List of Potential Areas in Innovation' was further developed as shown in Table 3.1 A more elaborate version of the table is given later when applicability of the technologies identified is assessed.

Table 3.1A – List of Potential Areas of Innovation

TECHNOLOGY	ASPECTS OF PROJECT APPLICABLE	FEATURES OF TECHNOLOGY	SOURCES
Up/Down construction	Substructure	1) Install perimeter sheet piles or diaphragm walls and interior substructure columns in steel or concrete. 2) Cast reinforced ground floor slab with access hole for excavation and start with superstructure construction. 3) Excavate first level of substructure to expose columns and perimeter wall and repeat for lower levels whiles superstructure proceeds.	) Process Of Innovation For Up/Down Construction at Rowes Wharf - C.B. Tatum J. of Const. Eng. & Mgt. – Vol. 115 No. 2, June 1989. 2) Const. Tech. for Tall Bldgs. Chew, Yit Lin Michael 2003, 2nd Ed,
Turn tables for equipment and trucks	Materials Handling	1) Customized rotating platform for maneuvering trucks in limited space. 2) Available diameter 10 - 60m. 3) Load capacity 10 - 150 tonnes.	http://www.solvinginc.com/contact_page.htm http://www.billferrell.com/mechanical_effects/turntables.htm http://www.360platform.com
Concrete handling using i) Trailer pump, ii) Pressure pipe and iii) Stationary placing boom	Materials Handling	Use of Putzmeister BSA 14000 HP-D or Equivalent with Putzmeister Placing Boom MX 38 or Equivalent and Pressure Pipe Anchored to the core for placing concrete.	http://www.putzmeister.com/products/large_line/index.cfm
Geothermal heat pump technology - deep vertical closed loop system.	Geothermal Technology	Heat exchange system consisting of 1) A number of water-to-air heat pump units inside a building. 2) A network of high-density, polyethylene piping buried in vertical bore-holes 150 - 300 feet deep as a circulating water loop. Constant temperature of the earth heats and cools the circulating water loops as needed to balance the buildings year round heating and cooling requirements.	1)Geothermal Energy – Utilization and Technology – Edited By M.H. Dickson and Mario Fanelli , Institute of Geosciences & Earth Resources – Pisa, Italy / UNESCO , Paris - France 2) http:// www.geo4va.vt.edu 3)http://www.tva.gov/
Peri skytable – Table forms technology	Superstructure	Proprietary innovative, modular, light-weight aluminum formwork used for slabs. Skydeck platforms are modeled from the inside. Lightweight aluminum components. SKYTABLE is connected to trusses that enable large units of up to 150 m^2 to be assembled and moved with a single crane lift. The simple pin and cotter pin connection allows a fast assembly process. The table can also be used for larger heights without any changes to the design with the MULTIPROPs used in a tower configuration.	1) Alternative Formwork System Evaluation By Todd Bookwalter 2) www.peri.ca. 3) Brochure of Peri Formwork Systems 4)http://www.peri.de/ww/en/projects.cfm/fuseaction/showreference/reference_ID/1032.cfm

Table 3.1B– List of Potential Areas of Innovation

TECHNOLOGY	ASPECTS OF PROJECT APPLICABLE	FEATURES OF TECHNOLOGY	SOURCES
Beeche Exterior Cladding Installation System	Superstructure/ Materials Handling	Proprietary innovative system for installing unitized curtain wall panels on high-rise buildings. Operations are carried out entirely from the exterior of the building through a rack-and-pinion system combined with a patented hoisting device. The system facilitates unloading, storing, hoisting and traversing panels to the installation point.	1) De-Coupling Cladding Installation from other High-Rise Building Trades: A Case Study by Iris D. Tommelein and Greg Beeche. 2) Beeche Exterior Cladding Installation System for High-Rise Buildings By Construction Innovation Forum. www.CIF.org
S.C.C - Self Compacting Concrete	Superstructure/ Materials Handling	Innovative concrete product that requires the addition of super-plasticizer and a stabilizer to the concrete mix to significantly increase the ease and rate of flow. It does not require vibration and achieves compaction into every part of the mould or formwork simply by means of its own weight without any segregation of the coarse aggregate. It differs from traditional concrete at the molecular interface between the cement compounds and the admixture polymers. The fluidity of SCC ensures a high level of workability and durability whilst the rapid rate of placement provides an enhanced surface finish.	1) Applications of Self-Compacting Concrete In Japan, Europe and the United States By Masahiro Ouchi, Sada-aki Nakamura, Thomas Osterberg, Sven-Erik Hallberg, Myint Lwin 2) Case Studies on Applying Best Practices to In-situ Concrete Frame Buildings Published by The Concrete Centre www.concretecentre.com 3) High – Performance Concretes: Creative Applications, New Opportunities By Ed Alsamsam, Beatrix Kerkhoff, Jamie Farny 4)http://www.concretecentre.com/main.asp?page=609
Prefabricated reinforcement	Superstructure/ Materials Handling	Consists of off-site preformed reinforcement mats for floors, walls, raft foundations, pile caps etc. Cage reinforcement for beams and columns. These should involve considerable repetition. These are formed through electrical - resistance welding or electric arc welding and are machine or manually welded depending on the scale and the relative advantages that can be derived.	Economic Assembly Of Reinforcement. By D.F.H. Bennett and L.A.M. MacDonald. British Cement Association Publication 97.321
Construction platform for deep excavation	Substructure	1) 12 No. Steel pipes as piles, driven or bored 90 feet into the ground. This supports a system of steel beams and 12.0m X 10.0m platform. The structure will be braced as excavation proceeds. The platform will take a clamshell to load haulage trucks at street level. The platform avoids the use of steep ramps for deep excavation in a congested site with limited footprint. 2) An alternative is a system of truss beams across one corner of the excavation and supported on buried foundations. This allows a free standing platform without supports in the deep excavation.	Construction Technology Of Tall Buildings: Chew, Yit Lin Michael :2003, 2nd Ed, 143 - 224, Singapore University Press, National University of Singapore ; Singapore ; River Edge, NJ : World Scientific, 2003., Singapore

The authors coordinated an extensive library search to identify new technologies relevant to the innovation needs assessment. The search was conducted in relevant journals and trade magazines, and in industry manufacturer and supplier information. The internet was also a valuable source of information on innovative technologies on an international basis. Details of identified technologies were recorded including sources and references.

The search or identification process was not intended to obtain 'ready-to-fit-technologies' but served as a platform to reason out significant changes required to the identified technologies to improve their applicability to the case study project. The authors devised a scoring scheme for the relevant factors in the preliminary assessment framework which was used by the group to screen the identified technologies to determine their level of applicability. A summary of the applicability of the 'candidate technologies' (Appendix A) was presented to the President & Chief Operating Officer and the Manager of Technical Services (Scott Construction Group) as part of the preliminary screening procedure. The initial review served several useful purposes: i) it exposed the construction manager to useful technologies that were hitherto unknown to them; ii) it helped to screen out technologies that could not be directly applied; iii) it provided additional insights on the identified technologies in relation to the project constraints and in fact helped to tease out constraints; vi) it provided feedback from the construction manager on the work of the student team; v) it elicited information on revised project conditions, designs, requirements and schedule that impacted on the assessment of innovative technologies; and, (iv) it helped with brainstorming on the applicability of the proposed technologies and assisting with the development of new ideas.

Based on the feedback from the construction manager the enhanced a further information search and analysis of the candidate technologies. Technologies that were clearly not applicable were discarded. Beyond the preliminary screening, further analysis and evaluation of the various innovative schemes was carried out by the authors. The Chairman and Chief Executive Officer (C.E.O) was briefed in an informal session while a third presentation was made to the Manager of Technical Services. With an encouraging response from the construction manager, faculty members of the construction management group initiated an additional investigation into facilitating construction innovations with 4-D CAD (3-D Modeling with 'Repcon' Project Management & Scheduling System).

Thus, the last presentation (prior to the submission of this work) was made by two faculty members (construction management group) and three graduate students.

In attendance from Scott Construction Group were the Chairman and Chief Executive Officer (CEO), the President and Chief Operating Officer (COO), the Vice President, the Manager of Technical Services and the Project Director (Hotel Georgia). The use of 4-D CAD for assessing innovation is not within the scope of this thesis.

The views and perspectives of other stakeholders (Developer, Designers, and Sub-trades etc.) were obtained through Scott Construction Group. Due to their unique position as construction managers they were able to provide feedback of those stakeholders.

3.3 Project Constraints

As emphasized in the literature review, the identification and assessment of potential innovations should be geared towards the particular constraints that characterize a project. As part of this exercise, it is important to distinguish between soft and hard constraints, with the former referring to constraints that potentially can be adjusted or removed. Summarized in Tables 3.2A& 3.2B is the set of constraints identified, by the authors and confirmed by the Construction Manager, as being relevant to the scope of this study.

Table 3.2A Project Constraints

Key Project Constraints	Description
Time - Project Schedule	Construction was scheduled to commence on 1/10/07 (postponed from 01/08/07) and the hotel component is completed in time for the Vancouver Winter Olympics. The project involves the construction of a 47 story high-end boutique hotel / commercial offices (level 1 to 13) and residential units of international class (level 14 to 46). The time constraint is compounded by construction on a 'brown-field' site which requires extensive demolition, shoring, underpinning and reconstruction.
Time - Schedule in relation to inclement weather	Site demolition of an existing concrete parkade was to start in August, now in October, 2007. Excavation and substructure works will peak in the winter period November – January. Rain, snow and the predominant ground material of sandstone with silt can easily turn into a 'pool' of mud under the weight of construction equipment.
City by – laws	Project is located at the commercial heart of Downtown with adjacent hotels. By-laws restrict noise related construction to the hours of 8:00 am – 4:00 p.m. weekdays, reduced hours on Saturdays and work not permitted on Sundays. The critical activities of – excavation, shoring and concrete works are substantially affected.
Traffic access	The project is located in an area of high vehicular and pedestrian traffic. Access is from a 'congested' downtown street and a narrow-lane (19ft. 6in. wide) that must be kept open to other users. Constraint on the movement of delivery and removal trucks affects the speed of construction. Construction work covers the entire site and no adjacent areas for storage (temporary or permanent), staging and maneuvering of construction equipment exist.
Airspace rights for tower crane	A limitation in airspace rights over adjoining properties has considerable effect on the type of cranage and vertical material movement.

Table 3.2B Project Constraints (Contd)

Key Project Constraints	Description
Easement for shoring	The subterranean structures of surrounding properties limits easement rights and pose constraints on the type and methods of shoring, underpinning and settlement control for the project. Geothermal system is affected and ultimately the time and cost of its installation.
Requirements for partial occupancy and construction strategy	The need to use the existing hotel and part of the tower (partial occupation) for the 2010 Winter Olympics before final completion will affect the construction strategy and sub-optimize the construction schedule. Ideally all aspects of the tower (substructure and superstructure) should precede corresponding works on the low-rise hotel. However, the request for partial use and physical constraints means that no part of the substructure can be left behind even though the tower is critical. This poses the question: "What innovative process can speed-up the entire construction of the substructure to compensate for 'time losses' due to this special requirement?"
Variability in geometry.	Varying shape and size of the superstructure floors for the tower limits the benefits of repetition and learning curve effects in construction.
Labor shortage	There is a shortage of skilled labor in general and in particular, acute shortages of ironworkers for rebar work. This can compensated for in part by the recruitment of relatively less experienced workers. There is a negative effect on construction floor cycle times and overall project schedule. This poses the question: "What technologies and construction methods can offset the resulting low productivity and time loss due to unskilled labor?"
Prevailing economic trends – inflationary pressures in construction & interest rates	Inflationary pressures are very high in the construction sub-sector with the attendant high cost of construction related services, activities, labor and finance. Monthly financing costs on average will be approximately $1 million. The client is prepared to tradeoff financing costs against construction costs (from innovations) to speed project delivery, provided time savings are certain.
Attitudes of local contractors	There is a general lack of innovation and a very risk-averse-attitude-of the part of local construction trades. This requires 'innovative management and contractual arrangements to make new methods acceptable and reduce the 'risk premium' that will be passed on to the client/construction manager by the local trades. Hence risk management becomes a key part of innovation assessment.

3.4 Assessment of Innovations for the Case Study Project

We have adopted a two-tier approach for the evaluation and made use of a list of generic factors for assessing the innovations identified. For the preliminary screening phase, the primary perspective is that of the project organization with emphasis on factors that will maximize potential incremental benefits in terms of time and cost. Innovative schemes that successfully pass through will be evaluated in detail at the second stage.

The assessment framework adopted represents an extension of the work of (AboMoslim & Russell, 2005), with the extension being a 'fine-tuning' of their factors to suit the specific project conditions and requirements of the case study project. The (AboMoslim & Russell, 2005) framework emphasis on a component/system innovation that examines prefabrication of building components and sub-units whiles the thrust of this thesis is on construction process innovation. Use is made of the generic criteria (Stakeholder factors, Engineering and Technical Factors, Construction Factors, Logistics and Personnel and Primary Project Goals) in the (AboMoslim & Russell, 2005) framework, while the detail factors have been re-defined to suit a construction process innovation. A detailed comparison of two schemes is indicated in Table 3.3. The revised factors have been further defined and used to form 3 filters to screen the technologies identified in Table 3.1. A second key refinement of the (AboMoslim & Russell, 2005) framework, is the use of a scoring scheme (positive (+ve) and negative (-ve)) for attributes of the 'candidate technologies'. In reality, the scoring scheme does not constitute a formulation for the preliminary screening, however, it facilitates and 'informed judgment' for analyzing the candidate technologies.

The preliminary screening framework involves a three-stage process as shown in Figure 3.1. The first filter determines the fit of the technology based on stakeholder requirements and objectives. Application of the second filter assesses the engineering/design feasibility, site conditions, construction factors, logistics and personnel issues. In particular, this filter seeks to determine, on a qualitative basis, how these factors enhance, inhibit or negate the potential incremental benefits of the innovative technology due to particular project constraints and conditions. The third filter deals with the impact of the technology on the primary objectives of the project, that is, time, cost, quality, environment and risk.

Each filter makes use of a number of attributes which taken together form the assessment criteria. While in general, generating quantitative values offers a higher measure of objectivity, resource constraints (time, cost, personnel) often limit the depth of the analysis conducted – qualitative judgment based on experience tends to be extensively relied upon. Thus, the use of qualitative attributes and values is most relevant for preliminary assessment, with the objective of providing a 'quick-but-reliable' evaluation to match a fast-paced project environment and the desire is to develop a short-list of most promising technologies. For hard non-negotiable factors/sub-factors, use is made of the boolean values of 'true' and 'false' which are equivalent to 'pass' and 'fail' or 'accept' and 'decline'.

The state (or values) of other factors/sub-factors are context dependent and can be determined as high, medium or low. Table 3.4 summarizes the attributes of the identified construction innovations.

Table 3.3 – Comparison of factors in AboMoslim & Russell Framework and the Revised Framework

Notation – **Bold and Underlined Factors** - Same in context for the two frameworks

CRITERIA	SUB-CRITERIA (FACTORS) IN ABOMOSLIM & RUSSELL FRAMEWORK (BUILDING COMPONENT/SYSTEM INNOVATION)	SUB-CRITERIA (FACTORS) IN REVISED FRAMEWORK (CONSTRUCTION PROCESS INNOVATION)
Stakeholder Acceptance	End Users	
	Developers/designers/contractors	**Developers/designers/contractors**
	Regulators & Building Codes	**Regulators & Building Codes**
Engineering & Technical Factors	Materials, System design, constructability, compatibility & Engineering Function	Engineering & Technical Feasibility
Production Factors	Location of Production, Production Means	Not Applicable
Technical Feasibility	Human resources, Local materials, Technology, Infrastructure	Not Applicable
Construction Factors	**Productivity, Safety,** Material Wastage & Prefabrication Degree	**Productivity**, Interaction & effect on other technologies, Congestion & **Safety**
Installed / In-use Factors	Sound/water/fire resistance, durability, & maintainability	Not Applicable
Logistics Issues	**Material Handling, Manpower & Equipment needs**	Procurement lead times, **Material Handling, Manpower & Equipment needs**
Primary Project Objectives	**Cost, Time, Quality/Performance, Risk and Environment**	**Cost, Time, Quality/Performance, Risk and Environment**

Figure 3.1 Preliminary Screening Framework (Adopted From AboMoslim & Russell, 2005)

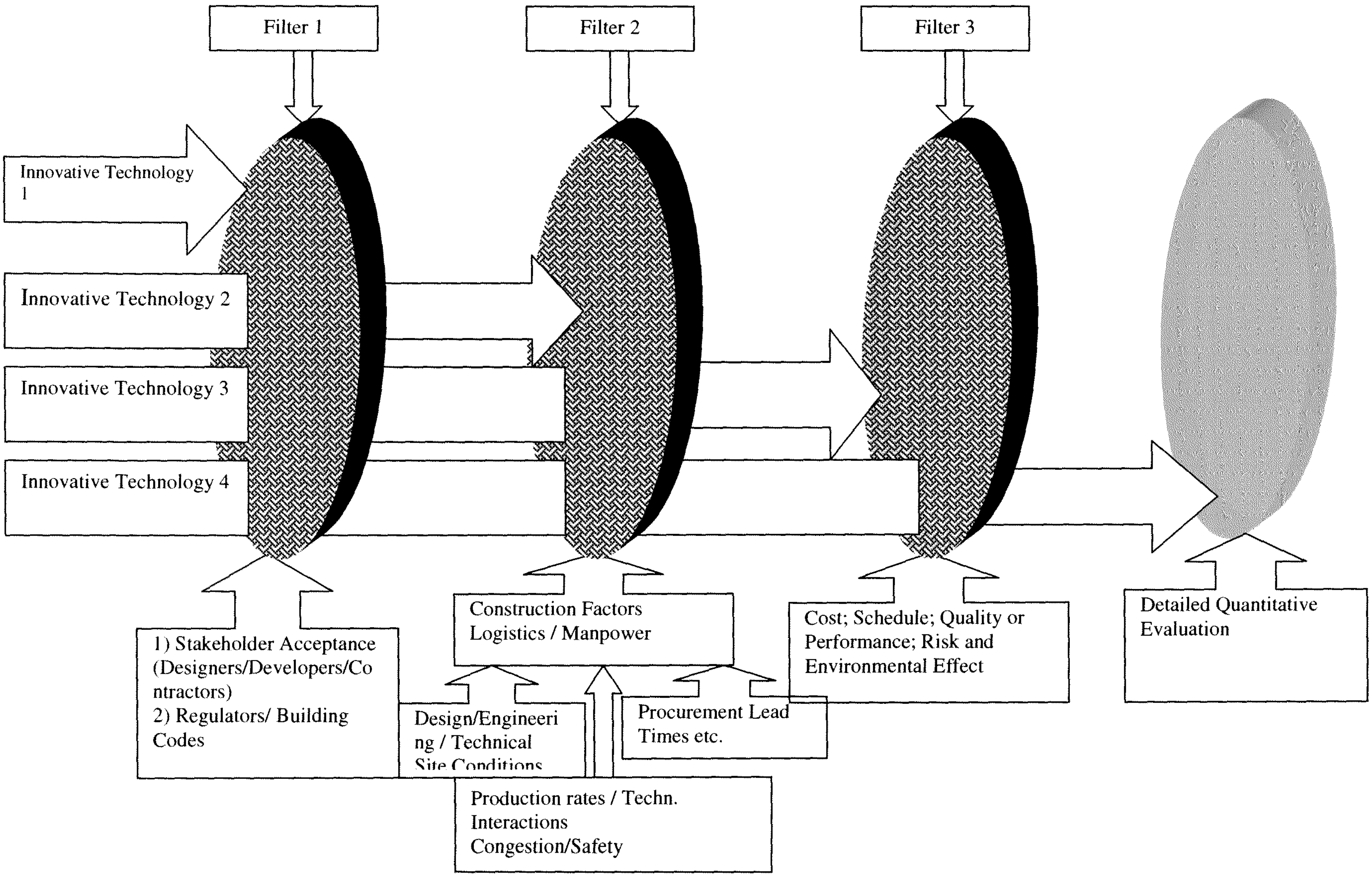


Table 3.4A - Summary of Preliminary Screening Framework (Adopted from AboMoslim & Russell, 2005)
(Notations: C. D. = Context Dependent)

CRITERIA / FACTORS / ATTRIBUTES	TYPE	STATES / VALUES			FILTER TYPE
1a.Stakeholder Acceptance					
1.1 Developers/designers/contractors	Hard / (Soft)	Acceptable / (Negotiable) – **Pass (P)**	Unacceptable/ (Non-Negotiable) – **Fail (F)**		**FILTER 1**
1.2 Regulators & building Codes	Hard / (Soft)	Acceptable / (Negotiable) – **Pass (P)**	Unacceptable/ (Non-Negotiable) – **Fail (F)**		
2a. Engineering & Technical Factors					**FILTER 2**
2.1Engineering/Design/ Technical Feasibility	Context Dependent (C.D.)	High	Medium	Low	
2.2 Site conditions	C.D.	High	Medium	Low	
2b. Construction Factors					
2.3 Production rates	C.D.	High	Medium	Low	
2.4 Interaction / Effect with other technologies	C.D.	High	Medium	Low	
2.5 Effects of technology on Congestion	C.D.	High	Medium	Low	
2.6 Effects on safety	C.D.	High	Medium	Low	
2c. Logistics & Personnel Issues	C.D.	High	Medium	Low	
2.5 Procurement lead time	C.D.	High	Medium	Low	
2.6 Manpower& Equipment	C.D.	High	Medium	Low	
2.7 Material handling & storage	C.D.	High	Medium	Low	

Table 3.4B - Summary of Preliminary Screening Framework (Adopted from AboMoslim & Russell, 2005)
(Notations: C. D. = Context Dependent)

CRITERIA / FACTORS / ATTRIBUTES	TYPE	STATES / VALUES			FILTER TYPE
3. Primary Goals					**F**
3.1 Cost	C.D.	High	Medium	Low	**I**
3.2 Time	C.D.	High	Medium	Low	**L**
3.3 Quality / Performance	C.D.	High	Medium	Low	**T**
3.4 Risk	C.D.	High	Medium	Low	**E**
3.5 Environment	C.D.	High	Medium	Low	**R**
					3

Filter 1 seeks to analyze an innovation from the perspective of various project participants. These perspectives and related criteria address: (i) acceptance by the developer, designer, construction manager and trade or sub-contractors; and, (ii) compliance with regulations of local authorities and building, engineering and design codes.

The second filter treats: (i) the engineering / technical features of the technology and project that determines their compatibility; (ii) the effect on production rates of the innovative process in comparison with 'conventional' methods, positive or negative integration of the technology with other methods, effect on site congestion and access and safety; and, (iii) the equipment and expertise (skilled labor) requirements and their availability.

Filter 3 explores the qualitative aspects of cost, time, quality/performance, risk and environment of each innovative scheme. Those technologies that survive the preliminary screening phase are then subject to detailed quantitative analysis - effectively a 4^{th} filter. Extensive time, cost and risk modeling may be involved in order to estimate incremental benefits and the certainty with which they can be realized.

3.5 Application of the Preliminary Assessment Framework

As noted previously, two objectives of this study are to assess specific innovations in the context of an actual project and in so doing test the usefulness of the framework set out by (AboMoslim & Russell, 2005) and where appropriate suggest modifications in terms of criteria and the manner in which values are expressed. In what follows, a description of each of the technologies examined is provided. This is followed by presentation of Tables 3.5A – 3.5I summarizing attributes and Tables 3.6A – 3.6D provides an assessment of qualitative criteria values.

3.5.1 Up - Down Construction

Up-down construction is a process innovation that does not follow the conventional approach of deep excavations but rather involves the construction of substructure and superstructure concurrently. It employs a number of methods: (i) permanent perimeter retaining wall construction through the use of one of concrete slurry wall, steel sheet piles or concrete diaphragm wall; (ii) pre-founded columns – structural columns or piles drilled and formed before basement excavation; and, (iii) a horizontal mining approach to substructure excavation. The technique has been extensively used in Japan and Europe, there has been limited application in the U.S., and no references were found indicating its use in Canada. This construction technique has been extensively discussed in (Becker, 1986; Chew, 2003; Tatum et al., 1989). A pictorial illustration of the use of 'Up-Down' construction is provided in Appendix B.

- Applying Filter 1 – Stakeholder Requirements/Objectives

  - The developer is interested in maximizing profits in the shortest possible time while maintaining a standard of quality that enhances their reputation. Having the hotel component of the development operable for the 2010 winter Olympics is of crucial importance. Thus, from the developers' perspective, 'Up-Down' technology is acceptable so long as the schedule savings are certain and the cost is acceptable.

  - The interest of the engineering design professionals is to improve reputation and profile in the industry, minimize project duration and limit their exposure. Local engineering professionals have the expertise to handle this technology and find the challenge acceptable.

  - The construction manager, while acknowledging the possibility of schedule savings, expressed serious reservations on the outcome due to (i) incomplete geotechnical details; and, (ii) lack of experience and high risk perception of the local trades.

  - The local subcontractors/ trades indicated a lack of familiarity with the technology and attached a high risk tag and a 'no go attitude' to the technology. Therefore, the use of 'Up-Down' technology on this project failed because it did not meet key stakeholder acceptance. While 'Up-Down' construction did not successfully pass through filter 1, to demonstrate the usefulness of the preliminary screening framework the technology was assessed further using filters 2 and 3.

- Applying Filter 2 - Engineering Feasibility/ Construction Factors / Logistics and Personnel Issues

    - There are competent design and engineering skills available locally for this technology.

    - An alternative substructure design is required, but likely can be done to suit the developer's needs and site conditions.

    - An initial geotechnical report indicates the predominance of siltstone and sandstone which is not suitable for 'up/down' construction (Geo-Pacific Consultants Limited, 2007).

    - A number of construction factors favor or inhibit 'up-down' construction:(i) favor – shorter overall project duration as substructure and superstructure are worked on simultaneously, (ii) favor – 'Up-Down' construction interacts positively with other materials handling, superstructure and geothermal technologies, (iii) inhibit - the likely congestion, traffic tie-ups from parallel activities of sub-grade and superstructure and the negative effect of an inconclusive geotechnical report combined with lack of local experience with mining technologies for the subsoil material, inhibit the use of the technology.

    - In terms of logistics and personnel, early arrangements for low clearance excavation equipment would be needed.

- Applying Filter 3 – Primary Goals

    - 'Up-Down' construction will have a positive effect on the overall schedule with no adverse effect on the quality of work or on the environment. The technology will be more costly than conventional methods with high geotechnical and substructure risks because of a lack of local experience with the approach.

- ‘Up-Down’ construction has a mix of positive and negative scores in all three filters. However, based on the adopted framework the technology is considered to have failed with filter 1

3.5:2 Geothermal Heat Pump Technology – Horizontal Closed loop System.

The Geothermal Heat Pump (GHP) is a heat exchange system consisting of a number of water – to – air heat pump units inside a building and a network of sealed high density polyethylene piping (HDPE) in a closed-loop system, which acts as the earth-coupled heat exchanger. The ground loop piping is filled with a working fluid that is continuously re-circulated without ever directly contacting the soil or water in which the loop is buried or immersed. Once filled with fluid and purged of air, nothing enters or leaves the closed loop. This eliminates the potential shortcomings of water quality and availability associated with open-loop systems (Dickson, Fanelli Mario, & UNESCO, 2003; U.S. Dept. of Energy, Virginia Dept. of Mines Minerals and Energy, & Virginia Tech,). Horizontal loops require the greatest amount of land surface area per system ton. Pipe loops are laid horizontally in trenches at a depth of 4 to 10 feet or drilled horizontally in to the sides of basement as in the case of the Hotel Georgia project. A detailed illustration of a Geothermal Heat Pump – Horizontal Loop System is available in Appendix B.

- Applying Filter 1 – Stakeholder Requirements/Objectives
    - This is a ‘green technology’ that has enormous social, economic and environmental benefits. All project stakeholders – Developer, Designers, Construction Managers, Contractors and Regulators are very supportive of its use.
- Applying Filter 2 – Engineering Feasibility/ Construction Factors / Logistics and Personnel Issues
    - Design and engineering skills are available locally and the technology can be customized to suit project conditions.

- The major factors that inhibit the use of horizontal loop system are: (i) the limited horizontal tract of land area available using closer spacing of horizontal pipes could exceed the thermal capacity of the soil and lead to a breakdown in the system; (ii) the substantial engineering input required to avoid underground service lines beyond the property line; (iii) unavailable easement rights for drilling beyond the project property line; and, (iv) system performance is susceptible to seasonal climatic changes.

- A number of construction factors favor use of the technology: (i) drilling and fixing of pipes at the basement level can be carried out as a parallel activity to substructure construction and will not affect the critical path or schedule of the project and (ii) minimal effect on site congestion, no adverse safety effects and it is compatible with the application of other technologies.

- The technology does not require substantial procurement lead time for engineering, design and installation. Skills and equipment are available for the technology and there are no adverse effects on materials handling. The technology has no negative effect on site infrastructure and equipment locations.

- Applying Filter 3 – Primary Goals

  - Life cycle cost savings as the substantial initial cost can be off-set by lower operating cost through energy savings. Drilling costs are lower than for the vertical system. There is a positive effect on overall schedule without additional costs as compared to the vertical system. Quality of work will not be affected though there could be a risk with performance. As a 'green technology' it has a positive impact on the environment and there are lower geotechnical risks as compared to a vertical system.

Based on an assessment of all three filters, the Horizontal Close Loop System – Geothermal Heat Pump Technology failed to pass 'Filter 2 – Engineering and Technical Feasibility'.

3.5.3 Beeche Exterior Cladding Installation System

The Beeche Exterior Cladding Installation System is a proprietary innovative system for installing curtain wall panels on high-rise buildings without a tower crane or man lift and on-floor staging. The system de-couples all work related to exterior panels from most other critical activities. Operations are carried out entirely from the exterior of the building through an aluminum space frame grid which creates a staging area for curtain wall panels combined with a patented hoisting device and a monorail system. The system facilitates unloading, storing, hoisting and moving panels horizontally to the installation point.
The conventional system of handling and installing panels on site requires tight co-ordination of the use of the tower crane and man-hoist. Staged panels occupy perimeter space on each floor that must be left unobstructed for use by other trades, while the installer needs working room to slide each panel individually to the edge of the floor prior to lifting it in place (Construction Innovation Forum, 2001; Tommelein & Beeche,). Selected details of the Beeche system are available in Appendix B.

- Applying Filter 1 – Stakeholder Requirements/Objectives.
    - All stakeholders acknowledged the innovativeness of the technology and the potential benefits in terms of materials handling, movement and efficiency of the tower crane that the Beeche system brings to the project.
- Applying Filter 2 – Engineering Feasibility/ Construction Factors / Logistics and Personnel Issues
    - The tower has a design that may pose considerable challenges: (i) varying or slanting geometry of the tower; (ii) cable-stayed (suspended) balconies; and, (iii) only two sides of the tower's perimeter would be accessible for the system. These challenges could be overcome by customizing the system but at additional expense.
    - The system has favorable construction factors: (i) improves the rate of installing curtain walls; (ii) frees up the tower crane and man hoists for other critical activities;

- (iii) frees up interior space for other trades to perform work more efficiently thereby reducing total construction costs; (iv) improves safety of the operations as Beeche Crab facilitates hoisting and installation at a reasonable distance away from the edge of slabs; and, (v) has minimal impact on the technologies use for other applications.

- In terms of logistics the technology is available and patented in the U.S. and may require substantial procurement lead time. Simple innovative equipment is involved and requires minimum skill to operate but there is no record of its use locally and local trades may not be familiar with it. Minimum on-floor staging and storage of panels improves material handling.

- Applying Filter 3 – Primary Goals:
  - The Beeche System is a proprietary installation system that is not available locally on a rental basis. It is therefore expensive and uneconomical for a project without large scale curtain wall panels. By using the technology the cost per unit of installing curtain wall panels may be higher than conventional methods. In terms of schedule, the efficient use of the tower cranes and material elevators for other critical activities significantly advances the completion of the project. Additional information and analysis would be required to determine if the resulting schedule savings is enough to pay for the extra cost.
  - The Beeche system eliminates breakage of glass curtain wall panels due to more effective handling methods.

The major inhibitors with the system are the additional expense to overcome engineering problems with the tower and the cost per unit of installation. Clearly cost is a major concern and the system therefore fails on 'Filter 3' of the screening framework.

3.5.4. Turntables for Equipment and Trucks

Construction turntables are customized rotating platforms that can accommodate construction equipment of various sizes and capacities. It is useful in maneuvering construction trucks and equipment situations of limited or constrained space. The turntables are available in varying diameters of 10 – 60 meters and load capacities of 10 - 150 tonnes. Appendix B provides pictorial details of construction turntables.

- Applying Filter 1 – Stakeholder Requirements/Objectives.
    - Construction stakeholders readily accepted the usefulness of the technology due to acute space limitations on the project. No consultation was held with other stakeholders as permanent design features are not affected.

- Applying Filter 2 – Engineering Feasibility/ Construction Factors / Logistics and Personnel Issues
    - The technology has been used in Canada (Roberts, 1976) and can be designed and fabricated to suit project conditions. It use does not require advance technical skills.
    - The system has favorable construction factors: (i) suitable for superstructure work, if coupled with a steel construction platform it can be useful for substructure work; (ii) enhances the rate of construction and solves the problem of congestion; and, (iii) interacts positively with other materials handling technologies - concrete pumps and construction platforms.
    - Once installed there are minimal requirements in terms of skills and equipment to operate. It enhances material handling, improves site infrastructure and equipment locations without any adverse effect on site safety.

- Applying Filter 3 – Primary Goals:
    - Cost of installation can be offset by the substantial benefits as the system will be used throughout the period of construction.

- However, would need careful modeling of construction operations to estimate accurately potential savings. It can be incorporated into the design as permanent equipment to facilitate deliveries.
- There is a positive effect on overall schedule. The quality of work will not be affected by technology and there is no adverse effect on the environment.

The turn table technology is very applicable to the project and passed through all three filters of the preliminary screening.

Findings from the processes of identifying, characterizing and evaluating/filtering innovations applicable to the case study project are summarized below in Tables 5A - 5D and Figure 3.2

TABLE 3.5A – ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	Engineering /Technical Factors	Construction Factors	Logistics, Manpower Issues / Project Goals
Up/Down Construction	1) Likelihood of a reduction in overall project schedule and related financial benefits. (+VE). 2) Eliminates the problem of substructure construction in inclement weather (+VE). 3) Enhances the need for partial occupation (+VE). 4) Eliminates problem of easement rights for shoring and underpinning (+VE). 5) Up/Down has never been used in Vancouver. High negative risk attitude by local trades and contractors (-VE). 6) Noise levels of sheet piling will impact negatively on city regulations for downtown construction (-VE).	1) Developer is interested only if it is feasible on the project and risk issues are addressed (-VE). 2) High risk concerns of local contractors (-VE). 3) Acceptable to Designers (+VE). 4) Construction Managers are uncertain with the outcome of using the technology (-VE). 5) Regulators are concerned with safety, quality and structural capacity and seismic considerations (-VE).	1) Available Design and Engineering Skills for Up/Down Construction (+VE). 2) Alternative design for substructure (-VE). 3) Geotechnical report indicates the predominance of siltstone and sandstone with cemented sandstone which is not suitable for Up/Down Construction (-VE).	1) Faster construction rate as substructure and superstructure are constructed simultaneously (+VE). 2) Interacts positively with other materials handling, superstructure and geothermal technologies (+VE). 3) Likely Congestion Of Sub-grade work. Traffic Tie-ups from parallel activities of sub-grade and superstructure erection (-VE). 4) Inconclusive geo-technical report and inadequate mining technologies for subsoil material in geotechnical report (-VE).	1) Need for early arrangements for low clearance excavation equipment (-VE). 2) Requires early and faster decision to adopt Up/Down construction (-VE). 3) Compound the problems of material handling and storage (-VE). 4) Negative effect on site infrastructure and equipment locations due to congestion (-VE). **PROJECT GOALS** 1) Substructure construction can more be costly than conventional methods (-VE). 2) There may be a positive effect on overall schedule (+VE). 3) Quality of work will not be affected by technology (+VE). 4) No adverse effect on environment (+VE). 5) High geotechnical and safety risks, local contractors risk averseness (-VE).

TABLE 3.5B– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment filters			
		Stakeholder Acceptance	**Engineering/ Design /Technical Factors**	**Construction Factors**	**Logistics, Manpower Issues / Project Goals**
Beeche Exterior Cladding Installation System	1) Higher installation rate for curtain wall panels with minimal disruption to other critical activities, enhances the project schedule (+VE). 2) Schedule deliveries do not depend on the availability of the hoist or tower crane resulting in efficient deliveries and materials handling (+VE). 3) Direct arrangements with the manufacturers for design and initial assembly of system, eliminates the risk averseness of local specialty contractors (+VE). 4) Varying geometry of the tower can have a negative effect on the installation rate and erode the benefits of the system (-VE).	Acceptable to all project stakeholders and participants. It does not require redesign of panels.	1) Varying geometry of the Tower and accompanying suspended balcony, with only two sides of the tower's perimeter being accessible provide substantial challenges which can be overcome at additional costs. (-VE).	1) Improves the rate of installing curtain walls (+VE). 2) No adverse effects on the application of other technologies (+VE). 3) Frees up interior space for other trades to perform work more efficiently. (+VE). 4) Improves safety of the operations as Beeche Crab facilitates hoisting and installation at a reasonable distance away from the edge of slabs (+VE).	1) The Beeche system is available and patented in the U.S., and may require some reasonable procurement lead time (-VE). 2) Simple innovative equipment is involved and requires minimum skill to operate (+VE). 3) Minimum on-floor staging and storage of panels and improved material handling (+VE). 4) System frees up tower crane and material hoist with a positive effect on site infrastructure and equipment (+VE) **PROJECT GOALS** 1) Proprietary system that cannot be used on rental basis. It is therefore expensive and uneconomical for a project without large scale curtain wall panels (-VE). 2) Availability of tower cranes and material elevators at the site significantly advances the completion of the project (+VE). 3) Eliminates breakage of glass curtain wall panels due to more effective handling methods (+VE). 4) No risk and environmental effects associated with the use of the system (+VE).

TABLE 3.5C– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	**Engineering/ Design /Technical Factors**	**Construction Factors**	**Logistics, Manpower Issues / Project Goals**
Peri Skytable – Tableforms Technology	1) Reduces time for flying and forming for concrete pours. Reduced 'floor cycle times' and enhanced project schedule (+VE). 2) Large size panels reduce fly-time and minimize the disruption to traffic. (+VE). 3) Flexibility in form arrangement reduces the effect of variability in floor geometry (+VE). 4) Direct arrangements with the manufacturers for design and initial assembly of system, eliminates the risk averseness of local subcontractors (+VE). 5) Problem of airspace rights can affect the size of panels and erode the benefits of reduce flying time (-VE).	Acceptable to Construction Manager.	1) Flexible system that facilitates the zoning of floor slabs and enhances planning to reduce floor cycle times (+VE). 2) Technology is available in Canada by Peri Formwork System and can be customized for projects (+VE). 3) Capable of overcoming the physical limitations of restricted sites (+VE).	1) Technology facilitates larger units of up to 150 m^2 to be assembled and moved with a single crane lift and thus increases the speed of construction (+VE). 2) No adverse effects on the application of other technologies (+VE). 3) Fewer props increase working space, reducing congestion and further resulting in time savings for forming and striking (+VE). 4) Sky-deck platforms are modeled from the inside of the building, site personnel are therefore behind the edge of the building in a safe position. The system therefore improves safety (+VE).	1) Available locally from Peri-Formwork System and can be supplied with reasonable notice (+VE). 2) Skill labour supplied 3) Light-weight aluminum components enhance material handling, fast delivery and offsite storage (+VE). 4) Reduced flying time will improve the efficiency of tower crane. (+VE). **PROJECTGOALS** 1) Peri is an expensive proprietary system. It is cost effective only if there is sufficient time-cost –trade – off (-VE). 2) Fast striking and removal due to drop-head contributes to schedule savings (+VE). 3) Excellent quality and performance - SKYTABLE can be used for all decks including sloped ramps (+VE). 4) Minimal risk and environmental effects (+VE).

TABLE 3.5D– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	Engineering/ Design /Technical Factors	Construction Factors	Logistics, Manpower Issues / Project Goals
S.C.C. - Self Compacting Concrete	1) Rate of concrete placement increases with a decrease in floor cycle times (+VE). 2) Avoiding concrete vibration eliminates or reduces noise and allows concrete operations at early and late hours without contravening city by-laws. It will facilitate concrete operations at periods of minimum downtown traffic (increased access for concrete trucks) further enhancing the project schedule (+VE). 3) Reduced labor in concrete operations reduces cost and site congestion (+VE). 4) There is a positive effect on project schedule (+VE).	Acceptable to Construction Manager.	1) Concrete is flowable enough to be self compacting and require no vibration. Strength development characteristics similar to conventional mixes. Places evenly amid heavy reinforcement and gives a good quality finish (+VE). 2) The basic issue of appropriate design mix can be solved with research institutions and private firms with commercial interest in the technology. (For example, Lafarge Canada Inc.) (+VE).	1) Elimination of vibration and a flowable concrete improves the rate of concrete placement for heavily reinforced elements. (+VE). 2) Combines favorably with other concrete handling technologies such as pumping (pumping improves the quality of concrete) (+VE). 3) With the elimination of vibration there could the possibility of placing concrete at non-peak times. This can reduce congestion at the site (+VE). 4) Improves safety as placing operation is simplified (+VE).	1) There are local concrete companies capable of supplying self compaction concrete to the required specifications without lengthy procurement procedures (+VE). 2) No special equipment is required. (+VE). 3) Minimal effect on material handling (+VE). 4) Use of tower crane and hoist may be spread out to longer hours therefore optimizing the use of site infrastructure (+VE). **PROJECT GOALS** 1) Very costly as compared to 'conventional' concrete. The additional cost cannot be offset by the elimination of vibration (-VE). 2) Positive effect on overall schedule (+VE). 3) SCC has excellent structural qualities and finish (+VE). 4) No risk and environmental effects associated with the use of the S.C.C. (+VE).

TABLE 3.5E– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	Engineering/ Design /Technical Factors	Construction Factors	Logistics, Manpower Issues / Project Goals
Prefabricated R e-inforcement	1) Increases the rate of placement of re-bar much faster than the conventional method of fixing loose bars at the workface **(+VE).** 2) Reduces the problem of site congestion and the lack of storage space with faster delivery and placement of re-bar **(+VE).** 3) Reduce the negative effect of shortage of experienced re-bar workers **(+VE).** 4) Simple technology that is acceptable to subcontractors without a 'negative risk posture and premium' **(+VE).** 5) Varying shapes and sizes of superstructure floors for the tower reduces the benefits of repetition necessary for prefabricated re-bar **(-VE).**	Acceptable to all project stakeholders and participants.	1) Simple technology that can be implemented locally without complex technical, equipment and labor input **(+VE).**	1) Faster production rates for re-bar work **(+VE).** 2) No adverse effect on other technologies **(+VE).** 3) Reduces Congestion on site **(+VE).**	1) Need for Structural Engineers and Designers to consider prefabricated re-bar early in design process for adequate detailing. Early involvement of re-bar subcontractors or fabric manufacturers will achieve best savings **(-VE).** 2) May not require substantial equipment both off-site and on-site **(+VE).** 3) Enhances material handling and storage **(+VE).** 4) No adverse effect on site infrastructure and equipment locations **(-VE).** **PROJECT GOALS** 1) Tonnage fixed per man day can be up to nine times that of loose bars and more than justifies the additional cost of off-site fabrication **(+VE).** 2) Positive effect on overall schedule **(+VE).** 3) Improved quality from off-site controlled assembly **(+VE).** 4) No adverse effect on environment - reduced material wastage **(+VE).** 5) Minimal risk of non-standard mats and cages for adequate repetition and economic production **(-VE).**

TABLE 3.5F– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	**Engineering/ Design /Technical Factors**	**Construction Factors**	**Logistics, Manpower Issues / Project Goals**
Turntables for Equipment and Trucks	1) Solves the problem of a restricted site and lack of space for maneuvering trucks; decreases the turn-around-time for delivery, removal and concrete trucks **(+VE).** 2) Indirectly reduces overall project schedule **(+VE).** 3) Installed by the General Contractor or Construction Manager for use by sub-contractors and trades this eliminates the risk averseness of sub-contractors and trades **(+VE).**	Acceptable to all project stakeholders and participants	1) Technology is available locally. It is mostly custom-made and does not require advance technical skills **(+VE).**	1) Suitable after construction of floor slab of level 1. May be suitable for substructure work when used with a construction platform **(+VE).** 2) Enhances the rate of construction and solves the problem of congestion **(+VE).** 3) Interacts positively with other materials handling technologies - concrete pumps, construction platforms **(+VE).** 4) No adverse safety effect **(+VE).**	1) Requires substantial procurement lead time if benefits are to be maximized **(-VE).** 2) Minimum requirements for skill and equipment to use (after installation) **(+VE).** 3) Enhances material handling **(+VE).** 4) No effect on site infrastructure and equipment locations **(+VE).** **PROJECT GOALS** 1) Substantial installation cost **(-VE).** 2) Positive effect on overall schedule **(+VE).** 3) Quality of work will not be affected by technology **(+VE).** 4) No adverse effect on environment **(+VE).** 5) Minimal risk of operation failure **(-VE).**

TABLE 3.5G– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	**Engineering/ Design /Technical Factors**	**Construction Factors**	**Logistics, Manpower Issues / Project Goals**
Geothermal Heat Pump Technology - Deep Vertical Closed Loop System.	1) Eliminates problem of easement rights and limited space for horizontal pipe system (+VE). 2) Use of low clearance drilling equipment could result in a positive impact on the project schedule (+VE).	Acceptable to all project stakeholders and participants	1) Technology is available locally. Custom-made and does not require advance technical skills (+VE). 2) Inconclusive geotechnical report may affect cost of drilling if extensive rock formation is encountered (-VE).	1) Drilling and fixing of pipes at basement can be carried out as a parallel activity to the superstructure (+VE). 2) Minimal effect on site congestion (+VE). 3) No adverse effects on the application of other technologies (+VE). 4) No adverse safety effects (+VE).	1) Technology is available locally and does not require substantial procurement lead time (+VE). 2) Skills and equipment are available for the technology (+VE). 4) No effect on site infrastructure and equipment locations (+VE). **PROJECT GOALS** 1) Substantial initial cost can be off-set by lower operating cost and energy savings (+VE). 2) There may be positive schedule savings if low clearance drilling equipment is used (+VE). 3) Quality of work will not be affected by technology (+VE). 4) As a 'green technology' it has a positive impact on the environment (+VE). 5) Substantial geotechnical risks (-VE).

TABLE 3.5H– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	**Engineering/ Design /Technical Factors**	**Construction Factors**	**Logistics, Manpower Issues / Project Goals**
Construction Platform for Deep Excavation	1) With adequate planning and a complement of equipment it speeds up the excavation process and accelerates overall project (+VE). 2) Reduces the problem of access and congestion as the movement of dump trucks can be well planned (+VE). 3) Eliminates concerns for deep excavation with steep ramps for dump-trucks (+VE).	Acceptable to Construction Managers. Excavation Sub-Contractors appreciate the risks related to using conventional ramps for dump trucks in the peculiar project constraints (+VE).	Technology is available locally. Custom-made and does not require advance technical skills (+VE).	1) Increase the rate of excavation with a faster construction rate (+VE). 2) Does not impede the use of other innovative technologies except Up/Down construction (+VE). 3) Reduces congestion of Sub grade work and access for dump trucks (+VE). 4) Reduces safety concerns of using steep ramps of over 60% grade for dump trucks (+VE).	1) Does not require long procurement lead time (+VE). 2) Skills and equipment available for the technology (+VE). 3) No adverse effects on materials handling (+VE). 4) Improves site infrastructure and equipment locations (+VE). <u>**PROJECT GOALS**</u> 1) Initial cost can be off-set by risk and cost premium (+VE). 2) Positive effect on overall schedule (+VE). 3) Quality of work will not be affected by technology (+VE). 4) No adverse environmental impact (+VE). 5) Minimal operational risks (+VE).

TABLE 3.5I– ATTRIBUTES OF PROPOSED CONSTRUCTION INNOVATIONS

Technology	Project Constraint(s) Positively or Negatively Impacted by Technology	Assessment Filters			
		Stakeholder Acceptance	**Engineering/ Design /Technical Factors**	**Construction Factors**	**Logistics, Manpower Issues / Project Goals**
3)Concrete Placement Using i) Trailer Pump, ii) Pressure Pipe and iii) Stationary Placing Boom	1) Increases the rate of placement of concrete much faster than the conventional method of skip and crane. Reduces 'floor cycle times' and enhances project schedule **(+VE).** 2) Negative impact on noise restrictions due to pumping **(-VE).** 3) Reduces the problem of site congestion (lack of space for concrete pump with outriggers) **(+VE).** 4) Not affected by adverse weather that may prevent the use of tower crane for placement **(+VE).** 5) Installed by the General Contractor or Construction Manager and thus eliminates the risk averseness of sub-contractors and trades **(+VE).**	Acceptable to all project stakeholders and participants	1) Skills available in the use of the system. Technology is available in North America **(+VE).** 2) Suitable for site due to limited space for pump trucks with outriggers **(+VE).**	1) Faster placement of concrete; reduction in floor cycle times **(+VE).** 2) Reduces site congestion **(+VE).** 3) Interacts positively with other materials handling technologies – turntables. **(+VE).** 4) No adverse safety effects **(+VE).**	1) Requires substantial procurement lead time **(-VE).** 2) Minimum requirements for skill and equipment to use (after installation) **(+VE).** 3) Enhances material handling **(+VE).** 4) No effect on site infrastructure and equipment congestion **(+VE).** **<u>PRIMARY PROJECT GOALS</u>** 1) Cost of placing cubic meter of concrete may be comparable to 'skip and crane' method **(+VE).** 2) Positive effect on overall schedule **(+VE).** 3) Quality of work will not be affected by technology **(+VE).** 5) Minimal risk of noise and operation failure **(-VE).**

Table 3.6A: Summary of Screening of Technologies

NOTATIONS: C.D. = Context Dependent

CRITERIA / FACTORS	ATTRIB-UTE TYPE	FILTER TYPE	UP – DOWN CONSTR.	HORIZONTAL CLOSED LOOP SYSTEM (G.H.P.)	BEECHE CLADDING INSTALLATION SYSTEM	PERI SKYTABLE – TABLE FORMS TECHNOLOGY	SELF COMPACTI-NG CONCRETE	PREFABRICATED RE-INFORCEMENT
			TECHNOLOGY					
1.1Stakeholder Acceptance Developers/Designers/Contractors	Hard	**FILTER 1**	**Fail**	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
Regulators/Building Codes	Hard			**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
2.1 Engineering & Technical Factors		**F**						
Engineering/Design /Technical Feasibility	C. D.	**I**		**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
Site Conditions	C.D.	**L**		**Fail**	**Pass**	**Pass**	**Pass**	**Pass**
2.2 Construction Factors		**T**						
Production Rates	C.D.	**E**			**Pass**	**Pass**	**Pass**	**Pass**
Interaction With other Technologies	C.D.	**R 2**			**Pass**	**Pass**	**Pass**	**Pass**
Effects on Congestion	C.D.				**Pass**	**Pass**	**Pass**	**Pass**
Effects on Safety	C.D.				**Pass**	**Pass**	**Pass**	**Pass**

Table 3.6B: Summary of Screening of Technologies

CRITERIA /FACTORS	ATTRIB-UTE TYPE	FILTER TYPE	TECHNOLOGY				
			HORIZONTAL CLOSED LOOP SYSTEM (G.H.P.)	**BEECHE CLADDING INSTALLATION SYSTEM**	**PERI SKYTABLE – TABLE FORMS TECHNOLOGY**	**SELF COMPACTING CONCRETE – S.C.C**	**PREFABRICATED RE- BAR**
2.3 Logistics & Manpower Issues		**FILTER 2**					
Procurement Lead Time	C.D.			**Pass**	**Pass**	**Pass**	**Pass**
Interaction with Other Technologies	C.D.			**Pass**	**Pass**	**Pass**	**Pass**
Effects Of Technology on Congestion	C.D.			**Pass**	**Pass**	**Pass**	**Pass**
Effects on Safety	C.D.			**Pass**	**Pass**	**Pass**	**Pass**
3 Primary Goals		**FILTER 3**					
3.1 Costs	C.D.			**Fail**	**Fail**	**Fail**	**Pass**
3.2 Time	C.D.						**Pass**
3.3 Quality / Performance	C.D.						**Pass**
3.4 Risk	C.D.						**Pass**
3.5 Environment	C.D.						**Pass**

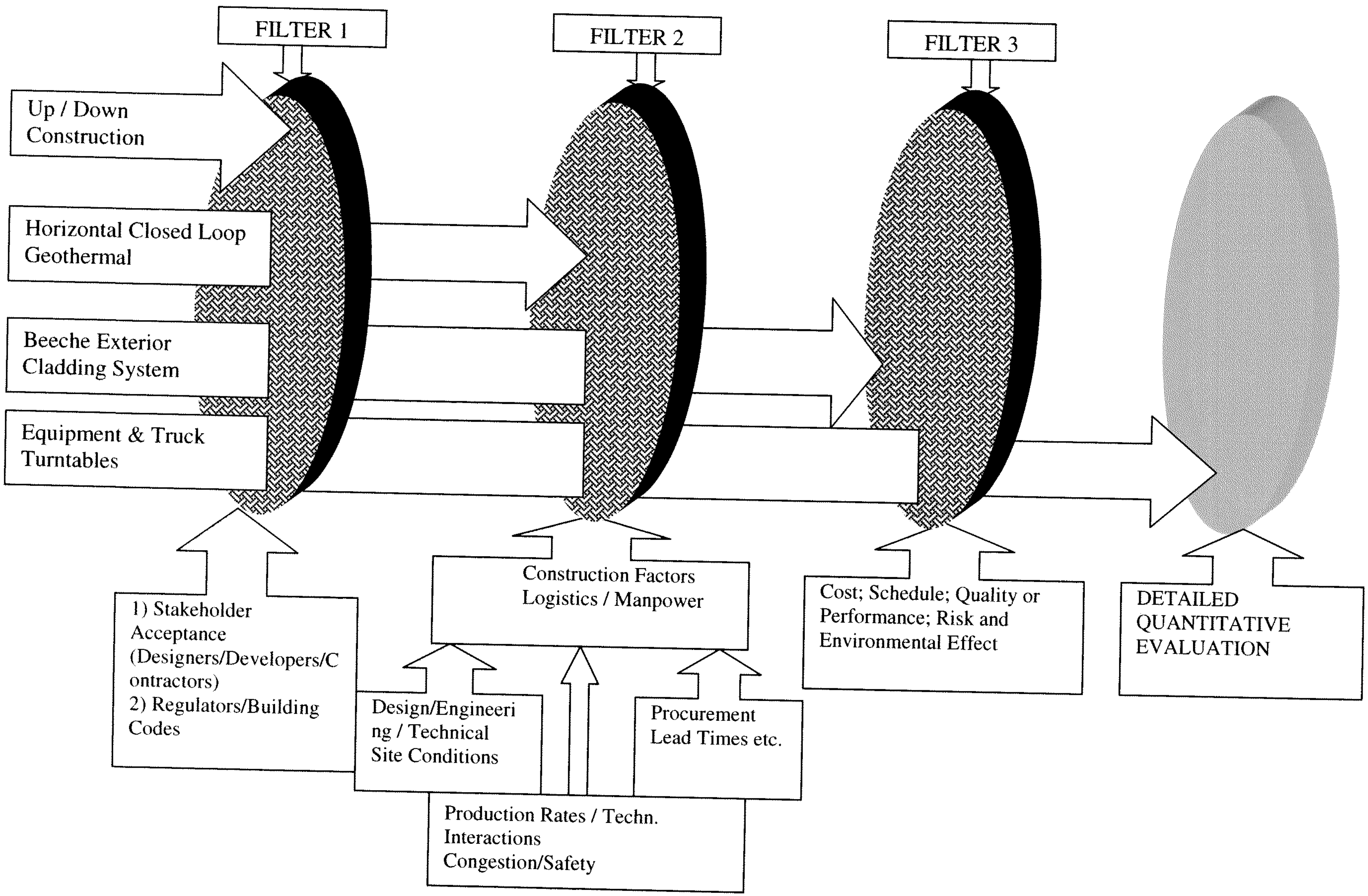
Table 3.6C: Summary Of Screening Of Technologies

CRITERIA/FACTORS	ATTRIBUTE TYPE	FILTER TYPE	TECHNOLOGY TURNTABLES	DEEP VERTICAL CLOSED LOOP SYSTEM – G.H.P.	CONSTRUCTION PLATFORM FOR DEEP EXCAVATION	CONCRETE PUMPING TECHNOLOGY
1.1Stakeholder Acceptance Developers/Designers/Contractors	Hard	**FILTE R**	**Pass**	**Pass**	**Pass**	**Pass**
Regulators/Building Codes	Hard	**1**	**Pass**	**Pass**	**Pass**	**Pass**
2.1 Engineering & Technical Factors		**F**				
Engineering/Design /Technical Feasibility	C. D.	**I**	**Pass**	**Pass**	**Pass**	**Pass**
Site Conditions	C.D.	**L**	**Pass**	**Pass**	**Pass**	**Pass**
2.2 Construction Factors		**T**	**Pass**	**Pass**	**Pass**	**Pass**
Production Rates	C.D.	**E**	**Pass**	**Pass**	**Pass**	**Pass**
Effect on other Technologies	C.D.		**Pass**	**Pass**	**Pass**	**Pass**
Effect on Congestion	C.D.	**R**	**Pass**	**Pass**	**Pass**	**Pass**
Effects on Safety	C.D.	**2**	**Pass**	**Pass**	**Pass**	**Pass**

Table 3.6D: Summary of Screening of Technologies

CRITERIA/FACTORS/ ATTRIBUTES	ATTRIBUTE TYPE	FILTER TYPE	TECHNOLOGY			
			TURN TABLES	DEEP VERTICAL CLOSED LOOP SYSTEM – G.H.P.	CONSTRUCTION PLATFORM FOR DEEP EXCAVATION	CONCRETE PUMPING TECHNOLOGY
2.3 Logistics & Manpower Issues		**FILTER 2**				
Procurement Lead Time	C.D.		Pass	Pass	Pass	Pass
Interaction with Other Technologies	C.D.		Pass	Pass	Pass	Pass
Effects Of Technology on Congestion	C.D.		Pass	Pass	Pass	Pass
Effects on Safety	C.D.		Pass	Pass	Pass	Pass
3 Primary Goals		**FILTER 3**				
3.1 Costs	C.D.		Pass	Pass	Pass	Pass
3.2 Time	C.D.		Pass	Pass	Pass	Pass
3.3 Quality / Performance	C.D.		Pass	Pass	Pass	Pass
3.4 Risk	C.D.		Pass	Pass	Pass	Pass
3.5 Environment	C.D.		Pass	Pass	Pass	Pass

Figure 3.2 - Preliminary Screening of Selected Technologies



CHAPTER 4[4]

4.1 Detailed Evaluation of Innovative Construction Technologies

The chapter provides an illustrative analysis that seeks to establish the process and tools for a quantitative evaluation of innovative technologies in the project context. Performing a detailed quantitative evaluation for the technologies identified in the case study is not covered by this thesis. The detailed analysis of one 'screened' innovation is carried out to outline the quantitative evaluation process at a micro level (activity level) and macro level (overall project level). Highlighted are; (i) the parameters of evaluation (work package duration and cost, capital and incremental cost, project duration and project NPV.), (ii) the quantum of data required at the early stages of planning; and (iii) the tools useful for the quantitative evaluation of each innovation. The other technologies are given a cursory treatment followed by a detailed tabular presentation of the parameters and tools required for their quantitative evaluation. Issues of risk are indicated as adjunct to the aforementioned parameters of evaluation but not given a detailed treatment in this analysis.

The purpose of the preliminary screening, based on informed or experienced-based judgment, is to test for feasibility and to provide evidence of sufficient tradeoffs between incremental costs and benefits to warrant an intense scrutiny of the technology. The second – tier evaluation does not require another multitude of factors or criteria for evaluation. Rather, it is based on key performance measures related to time, cost, revenue and risk. Cost can be measured in terms of constant dollar costs, current dollar capital costs and total capital costs including consideration of financing. Time should be measured by overall schedule savings while other considerations at this stage are treated as constraints, for example, safety and level of quality required.

Typical of most AEC projects, time constraints in the early planning and design stage of a project makes it difficult for project professionals to generate all of the details necessary for an in-depth analysis of the cost and benefits of an innovative construction technology.

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[4]A version of this chapter is being prepared for CSCE 2008 International Construction Conference. Whizz, A.D. Russell; R.C. Awuni and S.F. AboMoslim (2008).

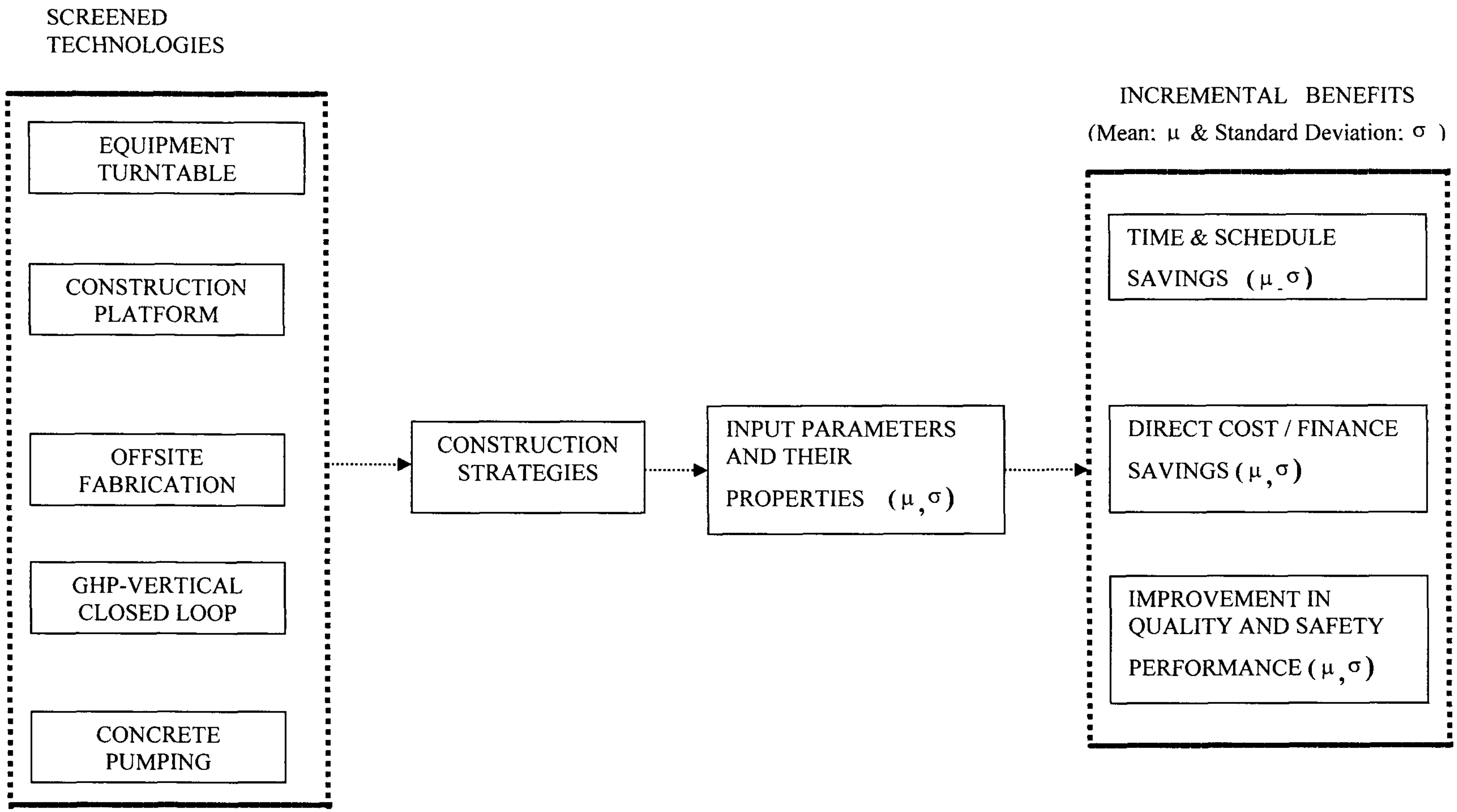
It is noted that the quantitative analysis in most cases has to be conducted in the absence of comprehensive data. That is, without prior experience with the technology, best estimate values are used, or ideally, estimates of the distribution of values. These values combined with simplified or higher level models constitute the tool kit for the quantitative assessment of likely performance, both on the input and output side. Shown in Figure 4.1 is an overview of the quantitative assessment process, at a very conceptual level, within the context of construction strategies relevant to the case study process. Note that estimates of mean and standard deviation are shown to indicate the need to predict the level of certainty in both output and input measures.

The performance models employed in the evaluation process must reflect the overall project context. For example, for the case of time savings, the innovation must be modeled within an overall, albeit simplified schedule, with interactions between the technology being assessed and other activities accounted for. This approach has been used by various researchers in a number of forms to bring clarity to the assessment of innovative technologies.

(Lutz, Chang, & Napier, 1990) considered the micro and macro level cost-benefits of new building technologies in aggregating the technical, economic (savings) and risk assessment factors of new technologies to obtain an 'overall assessment factor' (OAF). By examining the technology in detail and in relation to the project and the construction industry, a useful tool in the form of a 'Technology Index' (T.I.) was developed to enhance the comparison of alternatives and facilitate decision making on alternatives. Our own preference is not to reduce the assessment of a technology to a single aggregated number. Rather, we produce a vector of performance measures and allow the decision makers to prioritize their relative importance.

Figure 4.1 - Relationship between Screened Technologies,

Construction Strategies and Incremental Benefits



In conducting a quantitative assessment, we seek to answer the question: Does the technology contribute positively to the project performance with a high degree of predictability? In particular we seek answers to the following questions:

- Will the innovation result in overall scheduling savings/ faster delivery and/or increased productivity without bottlenecks or will it just result in improved efficiency of selected operations without affecting project duration?
- Will lower cost per unit of operation resulting from the use of a particular method translate into overall cost savings with a positive effect on other performance measures? Cost should be measured from a number of perspectives: direct constant and current dollar costs at the activity level, including interactions, and total cost at the project level including consideration of financing.
- Is there certainty in the 'projected' benefits in adopting a particular technology?

In the following section, we provide a detailed description of the performance measures that are used as a scoring scheme for assessing the innovative processes identified for the case study project and which successfully passed through preliminary filters 1 through 3.

4.2 Performance Measures for Detailed Evaluation of Technologies

4.2.1 Time/Schedule Performance

For the case study project, schedule-efficiency is a key factor in every decision. As indicated in the list of constraints, the project delivery focus is on meeting the deadline of partial completion and use for the 2010 Winter Olympics. The project can be described as being schedule driven on two fronts; the completion of renovation and construction of the low-rise hotel as required by the developers and partial completion of the tower such that regulatory authorities will allow operation of the hotel.

The importance of the 'time-objective' can be seen from several perspectives for the project: i) sufficient and satisfactory completion (as determined by regulators and developers) in advance of the Olympics marks the on-set of a major stream of revenue or cash inflows to the project due to high international patronage at premium rates; (ii) the use of the hotel for the Olympics serves as a platform to market the high-end residential 'condos' and allows the developer to maximize the values (and revenue) of these units; (iii) The project has a substantial financing cost per unit of time (about 1 million Cdn $ per month). Innovative technology that can positively result in significant time savings will represent attractive financial relief to the developer, provided any incremental cost associated with the technology can be paid for from the savings in financing costs.

4.2.2 Cost Effectiveness and Finance Savings

While the importance of time as a dominant factor in this project cannot be over emphasized, the developer and construction manager are cost-conscious in their bid to achieve timely delivery of the project. Therefore, the overall cost implications of each innovative method should be assessed, notwithstanding that significant time savings might be involved. Ideally, innovative schemes should contribute to lower or neutral costs including any negative impact on cost and schedule of other methods or operations.

4.2.3 Quality / Performance

The developers have targeted international patronage for both the hotel and the residential units. The project has high-end quality requirements typical of a traditional brand name reputation and the international hotel business. Innovative construction technologies should therefore meet or improve upon the quality required. Quality in this context is interpreted as satisfying project specifications (e.g. tolerances, uniformity of finish etc.).

4.3 Assessment of Quantitative Benefits of Selected Innovations Identified

Innovation can be evaluated from the perspective of the contractor, client, sub-trades etc. Costs, work package duration, schedule savings, financing cost, early revenue inflows, risk reduction etc. are basic parameters that would be considered by the key players (client, contractor, sub-trade etc.) in implementing an innovation beyond the preliminary screening.

In what follows, considerations involved in the quantitative assessment of benefits (positive and negative) for some the technologies identified are presented.

These considerations must be accounted for in modeling the relevant performance measures. One technology is taken through the procedure to demonstrate the potential treatment of screened technologies in a quantitative evaluation. Carrying out the evaluation is beyond the scope of this thesis. In addition to the foregoing, an overview is provided of the modeling effort for the other technologies identified. It is of interest to observe the range of analytical tools required for quantitative performance evaluation.

4.3.1 Quantitative Evaluation for Installing Platform for Bulk Excavation.

Two types of construction platform are applicable to the project: i) a raised steel platform, along one side of the proposed tower over the lane, to provide a staging area for deliveries. Based on a gantry-on-rail system with a hopper, non-concrete deliveries can be quickly discharged and temporarily stored without consuming crane time; and ii) a grade level steel platform so that excavation can proceed without the need for ramps; it will provide a working surface for an excavator with an extended arm or a clamshell excavator. Thus, dump trucks will not enter the site, but queue in the lane, thereby minimizing their turnaround time. On a comparative basis with the conventional alternative (i.e. deep excavation with ramps), construction platforms can speed up the deep excavation and result in schedule and cost savings while improving safety.

A detailed framework for quantitative assessment of the excavation platform strategy (as against the conventional method) is outlined below in some considerable detail. The purpose of doing so is to illustrate the kind of thought processes and modeling required for quantitative evaluation of strategy/innovation. Some what greater complexity is involved if two or more innovations are assessed simultaneously and they interact.

The primary perspective is that of the client; however the general contractor/construction manager (G.C. or C.M) and excavation trade perspectives are adopted as well in the assessment.

A) Performance Measures of Interest

A first step involves identifying quantitative measures of interest.

- Direct capital cost to client (increment over conventional)
- Total capital cost inclusive of financing costs to client (increment over conventional)
- Increment in Net Present Value (NPV) to client (inclusive of incremental revenue potential)
- Time savings (including work package time for sub trades)

B) Assumptions made and their reasonableness.

All assumptions made should be identified and their reasonableness assessed.

- High likelihood that by using conventional approach, the client will miss the deadline for having hotel operational for 2010 Winter Olympics.
- Shoring cost is identical for conventional & platform based excavation strategies and thus not considered in the analysis (in reality, there may be some interactions and differences).
- It will be possible to achieve balanced production rates between digging and trucking, such that digging work does not incur substantial idle time. Given the volume of ongoing work in Vancouver, this may not be achieved because of high demand for trucks.
- The duration of successor work will not be affected by its shift in time in time because of the shortening of excavation work or increased overlapping of successor and excavation work.

- Conventional alternative (deep excavation and ramps) is denoted (1) and Platform base (2).
- Base costs are estimated in constant dollars.

4.3.1.1. Macro level Analysis Framework –

A macro analysis deals with how the innovation or conventional alternative integrates with the overall construction approach so that time and cost performance of the overall project level can be assessed.

a) Time Models

Figure 4.2 shows the overall project schedule. All successor work is assumed to move as a single unit and its duration $\mathbf{T}_{SRF}$ is assumed to be independent of the excavation strategy used.

The nomenclature used is defined as:

T_{HO} = the date by which the hotel construction work must be completed in order to guarantee operation for the Olympics.

T_i = the date by which the hotel construction work must be completed – it is a function of the **ith** excavation strategy.

T_{ci} = the total construction duration – it is a function of the **ith** excavation strategy.

T_{SRF} = duration of the structural, rough-in and finishing work – assumed to be independent of excavation strategy.

D_{Ei} = duration of excavation phase – a function of the **ith** excavation strategy.

x_i = fraction of excavation that must be completed before successor work start.

T_{Ai} = absorption period for condo sales – a function of when the project is completed (before or after the Olympics).

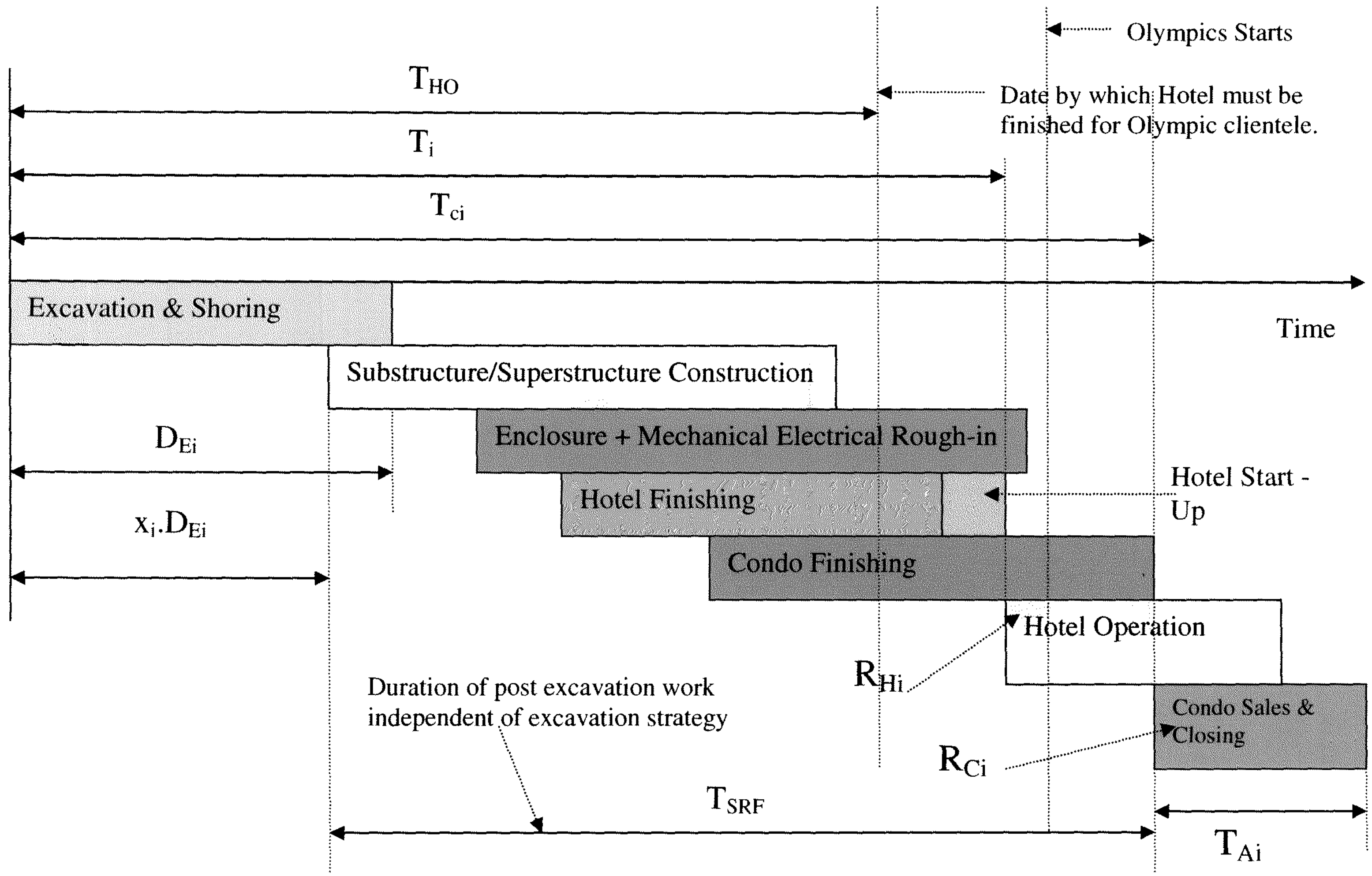
i = construction strategy alternative number (**i** = 1 corresponds to conventional method and **i** = 2 corresponds to the use of platform i.e. the proposed innovation).

R_{Hi} = hotel net operating income function for ith excavation strategy.

R_{ci} = condo net revenue function for ith excavation strategy.

Assume that the work packages detailed in Figure 4.2 remain the same and an evaluation is required to establish the corresponding constant dollar cash flow function (with escalation and cost of finance). The position of such a cash flow, in time is a function of the duration of excavation ($\mathbf{D}_{Ei}$) and the degree of overlap ($\mathbf{D}_{Ei} - X_i \cdot \mathbf{D}_{Ei}$). It is further considered that excavation acceleration strategy (as a result of the innovation) is sufficient to bring the start-up phase of the hotel to a date by which the hotel must be finished to capture Olympic clientele.

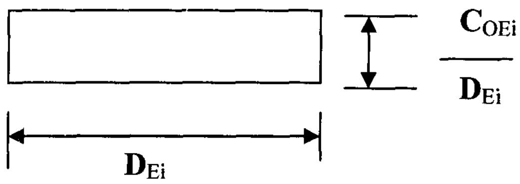
Figure 4.2 - Time Model



d) Cash flow Functions

Assumption: Costs first expressed in constant dollars with a uniform expenditure function. Adjustment to current dollars is a function of work timing. Revenues are expressed directly in current dollars.

i) Excavation



C_{OEi} = Constant $ cost of excavation to owner for the ith option. (Assume 100% financed)

Figure 4.3 – Excavation constant dollar expenditure function

ii) Remainder of construction work (Assume construction work is 100% financed)

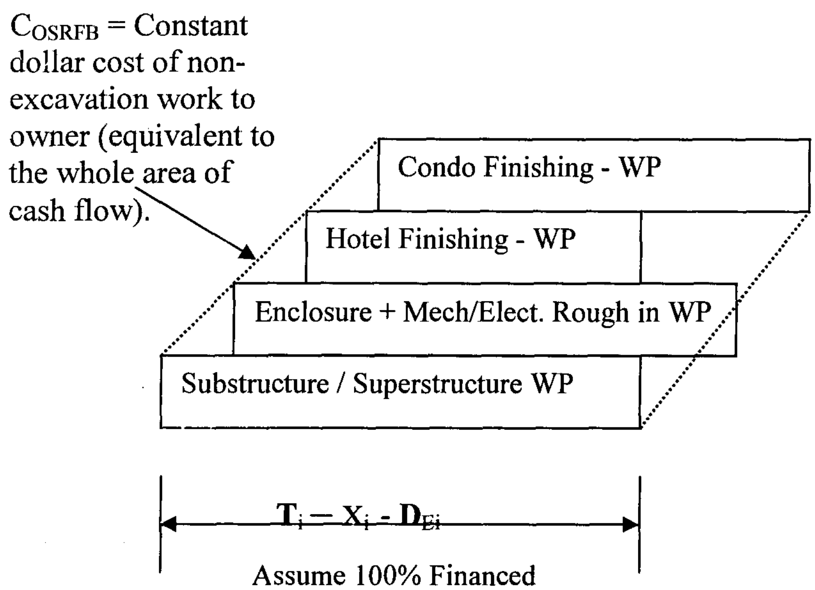


Figure 4.4 – Structural, rough-in and finishing expenditure function.

iii) Hotel Current dollar Net Operating Income Function, R_{Hi}

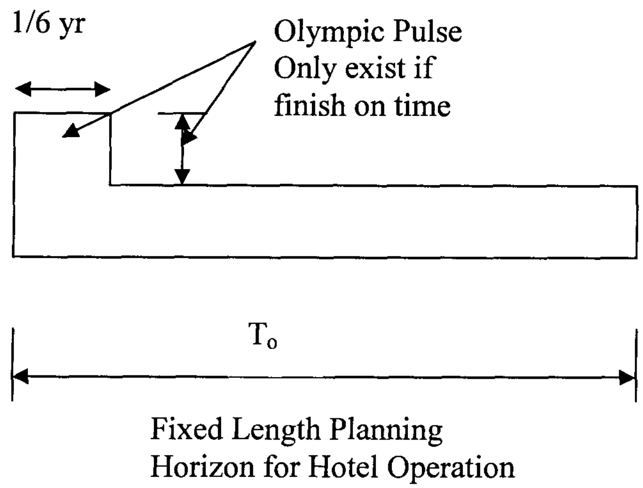


Figure 4.5 - Hotel current dollar net operating income.

Revenue Function for Condo Sales

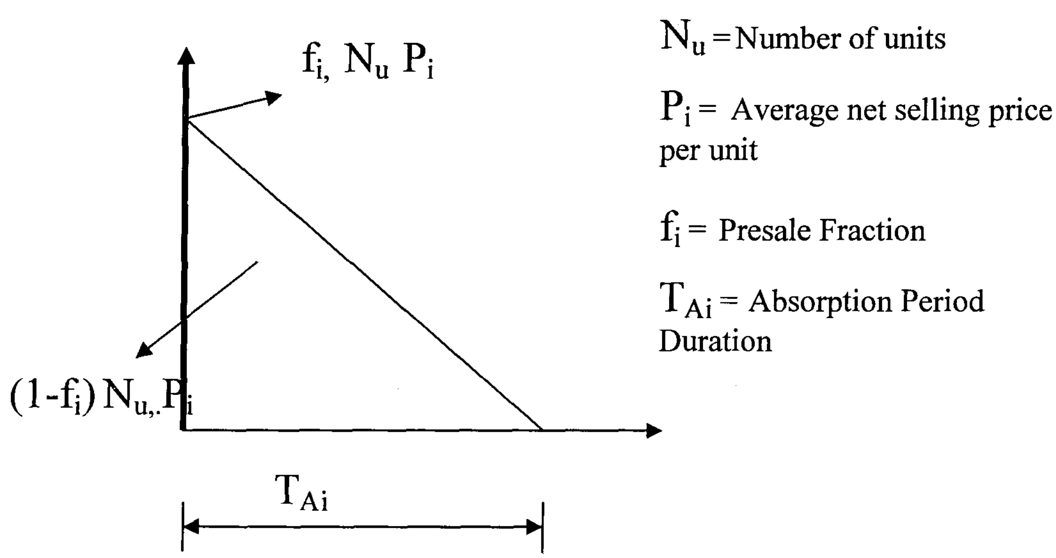


Figure 4.6 – Revenue Function for Condo Sales.

Note: f_i, P_i, T_{Ai} are a function of the completion date (project duration). Timely completion for the Olympics should help the market (and value) of condos with prospective international clientele and thus, increase f_i and shorten T_{Ai}. There could be other revenue functions e.g., parking, which could be affected by earlier completion, however, they have been ignored in this analysis.

Net Cash Flow Model

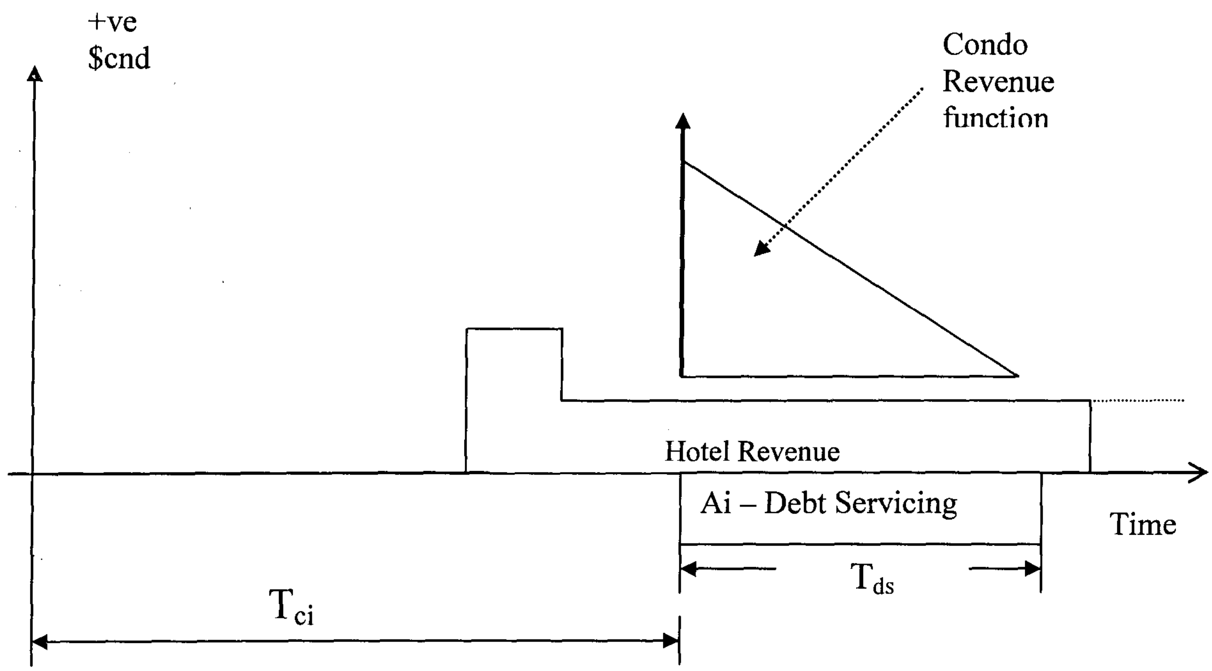


Figure 4.7 – Net cash flow model

A_i is a function of C_{OEi}, C_{OSRF}, i_c, T_{ds}, T_{ci} and θ

i_c = construction loan interest rate and permanent financing rate

r = client discount rate

θ = inflation rate for construction

T_{ds} = duration of debt servicing

Based on the net cash flow model, the Net Present Value (NPV) for each strategy (i.e. conventional and innovation) can be computed as NPV_i. Once it is established that the NPV for the construction platform (NPV_2) is greater than that of the conventional method (NPV_1) the innovation becomes an obvious choice. In the instance that the NPV of both strategies are equal (NPV2 = NPV1), the innovation should be preferred if its implementation will result in significant time savings (i.e. $T_2 < T_{HO}$).

Secondly by setting $NPV_2 = NPV_1$ a determination can be made of the upper bound on how much to pay for the innovative strategy (i.e. construction platform) as a function of the degree of shortening. Given the required time shortening, $T_i - T_{HO}$, an upper bound can be computed on excavation cost or maximum increment allowed (i.e. Δ C_{OE}). In addition there is the need to establish the certainty of achieving the time shortening (due to the innovation) by conducting a sensitivity analysis or probabilistic analysis.

4.3.1.2 Micro level Analysis Framework.

At the micro analysis level, one looks inside the excavation / shoring work package and models details of the process in order to estimate cost, duration and interfacing with successor work. Modeling the operation yields equipment spread details, production rates and labour requirements.

a) Evaluating Work Package Profitability:

Cost of Excavation to the client (for the ith strategy) denoted by $\mathbf{C}_{OEi}$

= $(1+\mathbf{P}_{Fi})$ $(1+\mathbf{O}_{Vi})$ [Labour ($\mathbf{L}_i$)+ Excavation Equipment Cost ($\mathbf{E}_{vi}$)+ Trucking Cost ($\mathbf{T}_i$)+ Temporary Materials ($\mathbf{T}_{mi}$)+ Indirects ($\mathbf{I}_i$)]

'$\mathbf{P}_{Fi}$' denotes profit margin and '$\mathbf{O}_{Vi}$' overheads expressed in fractional form.

In reality, profit expectations could be different for the alternatives. It might be higher for alternative 2, as trades recognize the benefits derived by the client and construction manager. In addition, if the innovation is believed to have greater risk than the conventional approach, $\mathbf{P}_{F2}$ could be greater than $\mathbf{P}_{F1}$.

Excavation duration ($\mathbf{D}_{Ei}$) is the maximum of either trucking duration or digging duration. It is however assumed production rates are balanced and trucking fleet is sized so that digging equipment is not idle.

$\mathbf{P}_{Ri}$ = Production rate can be determined from the relationship.

Productivity x Resource Usage Rate = Production Rate (e.g. m^3/day)

$$\text{Duration} = \frac{\text{Scope (e.g. } m^3\text{)}}{\text{Production Rate (e.g. } m^3\text{/day)}} = \text{working days}$$

i) **Labour**

Cost of flag persons, surveying – duration determined by production rate.

$\mathbf{N}_{Li}$ = Number of Personnel; CLi = Unit cost of labour per working day;

$\mathbf{D}_{EWi}$ = Activity Duration in working days;

Thus, labour cost, $\mathbf{L}_i = \mathbf{C}_{Li} \times \mathbf{N}_{Li} \times \mathbf{D}_{EWi}$

ii) **Excavation Equipment spread**

Depending on the alternative being examined, the equipment spread consists of hydraulic excavators, dozers (with rippers), blasting equipment, and clam shell excavators.

$\mathbf{C}_{Ei}$ = Unit Cost per working day of equipment spread;

Thus, excavation equipment spread cost, $\mathbf{E}_{vi} = \mathbf{C}_{Ei} \times \mathbf{D}_{EWi}$;

iii) **Trucking**

= Size of Fleet ($\mathbf{N}_{Ti}$) x Unit Cost of Equipment per day ($\mathbf{C}_{Ti}$) x Duration

Thus, trucking cost, $\mathbf{T}_i = \mathbf{N}_{Ti} \times \mathbf{C}_{Ti} \times \mathbf{D}_{EWi}$;

$\mathbf{C}_{T1}$ should equal $\mathbf{C}_{T2}$ (i.e. the unit cost per truck should be the same irrespective of the alternative used).

iv) Temporary Materials

($\mathbf{T_{mi}}$) – Applies to Alternative 2, and covers design, fabrication, installation and removal of the platform.

Assume office overhead rate ($\mathbf{O_{Vi}}$) and indirects ($\mathbf{I_i}$) are independent of the alternative used. The most significant test for both the macro and micro level analysis is the relative durations (in calendar time) of excavation for the innovation (platform) and conventional method ($\mathbf{D_{E1}}$ and $\mathbf{D_{E2}}$). Assuming that in both cases there is flexibility in sizing trucking fleet so that excavation equipment (and clamshell for alternative 2) will not be idle, the following conditions must be established in a quantitative evaluation to facilitate a choice of the innovation.

Tests of interest for determining the choice between the alternative are:

Prob $[\mathbf{NPV_2} \geq \mathbf{NPV_1}] \geq$ ¢NPV,

Prob $[\mathbf{T_i} \leq \mathbf{T_{HO}}] \geq$ ¢t,

Prob $[\mathbf{TC_2} \leq \mathbf{TC_1}] \geq$ ¢c,

in which TC_i refers to the total cost of the project, given alternatives **i,** and ¢**t**, ¢**c**, ¢ **NPV** are threshold values specified by the client as a function of their attitude toward risk.

Additional tests relate to the duration of the excavation phase and the degree to which excavation work and successor work can be overlapped.

4.3.2 Evaluation of Concrete Placement Technologies

Worthy of consideration here is the use of a trailer concrete pump ('Putzmeister BSA 14000 – HP-D' or equivalent) with a stationary placing boom ('Putzmeister Placing Boom MX 38'or equivalent) and a pressure pipe (anchored to the core of the tower) for placing concrete. This configuration is particularly useful for the 'tower' construction as compared to the traditional 'crane and skip' method. Concrete can be discharged into a stationary pump at the basement or ground level and pumped to over 300 m high. The placing boom at the receiving end can distribute the concrete over the entire floor plate of the tower.

The method will result in faster placement of concrete than the traditional 'crane and skip' method. It will lead to faster delivery; reduced floor cycle times and thus, schedule savings. There is the additional advantage of avoiding congestion with the use of pump trucks with outriggers on a restricted site. With a faster rate of placing concrete, the overall cost per unit of placing can be comparable to other methods. There is certainty of performance with this method. With an adequate delivery plan for concrete trucks, planned placement schedules can be achieved without much external influence (such as downtown vehicular traffic).

In terms of the quantitative evaluations of this alternative for concrete placing, cycle time and labour productivity are of critical importance. If floor cycle time could be reduced, and cycle time for follow-up work matched to this rate, then significant time savings could result. At the macro level of analysis, project duration and NPV are key performance variables.

At the micro level, productivity of those involved with concrete placement (verticals and slabs) is an important measure, as well as cost of a floor cycle and cycle duration. Again, certainty of performance is central to decision making – i.e. can the estimates of improved productivity and reduced cycle time be realized.

4.3.3 Evaluation of Construction Turntables

The use of construction turntables has the potential of reducing congestion and delivery times and speeding cycle times, thereby reducing project delivery time. By turning a truck around in 30 – 60 seconds, delays caused by lengthy maneuvering of trucks and trailers in confined construction spaces are avoided. A turntable is only a useful aid when coupled with other technologies which directly affect the construction rate. The physical conditions favor an enclosed location, indicating that the turn-table can only be used effectively with concrete pumping technology and with 'internal jump elevators' for moving materials, tools and small equipment. Thus, the challenge in assessing this technology involves the simultaneous treatment of one or more other technologies.

The design of the structure provides limited space at grade level to maximize the use of the technology. The maximum space available for a turntable is 40 feet wide and 25 feet high. A turntable of 35 feet can only be used by single trailer with a length of 35 feet and concrete trucks (31 feet long x 13 feet high).

The notable limitation in using the technology is that it cannot be installed for sub-grade construction and therefore cannot accelerate the construction of the sub-grade structure which is critical. In addition, the time savings in maneuvering of delivery trucks can be defeated by delays in vehicular traffic due the location of the project. This particular limitation is beyond the control of the project participants, except for the case where deliveries of material that can be temporarily stored can be made in off hours.

However, storage space on site is severely limited. Evaluation of this technology quantitatively, would require fine-grained modeling of material handling and would involve the use of queuing and or simulation models. There is low certainty that the technology can result in time or schedule savings i.e. the estimated time savings would be accompanied by a higher variance.

4.3.4 Evaluation of Jump Elevators

Involves running temporary elevators using the permanent elevator rails in the core of the tower. As the building progresses upwards, a tower crane can be used to hoist or jump the elevator machine room to the next higher level. For optimal results, the industry practice is to install the jump elevators at floor level 10 and to jump every 4 or 5 floors afterwards. Due to the particular design and size of the core and elevator shafts for the tower, only three elevator shafts of limited dimensions – 2.5m x 2.2m can be used as jump elevators. For the case study project, the system is only suitable for moving personnel, small equipment, materials and tools. As a result, jump elevators can only be used in combination with man-hoists. During peak construction hours, the use of jump elevators can provide a fast service for personnel to move to and from working floors, thus reducing idle labor hours. Savings in idle man-hours can translate into increased productivity, cost and schedule savings. However, quantifying the expected total man-hour savings against the total cost of installing and maintaining jump elevators is not straight forward, especially if external man-hoists or material hoists are used as well. Provided the use of the different means of vertical movement (for materials and personnel) is planned and adhered to, then there is predictability or certainty of performance and evaluation can be in terms of estimates of time and cost savings.

4.3.5 Evaluation of Vertical Closed Loop Geothermal System

A geothermal heat pump system using a vertical closed loop system is a second option of the Geothermal Heat Pump technology (GHP) described in the second chapter of this thesis. A vertical closed loop system requires pipes placed in vertical bore holes, drilled 500 feet from the foundation level of the basement. Use of a vertical system eliminates the problem of easement rights that accompanies use of a horizontal system. Drilling of vertical boreholes must be carried out after bulk excavation and preferably before the construction of verticals for the basement parkade.

The resulting impact on the project schedule and financing cost could erode much, if not all, of the long term operating benefits of the technology. Use of low clearance drilling equipment can eliminate the drilling activity from the critical path. Drilling can be started after completion of 2 – 3 floors of the substructure. Schedule savings will be achieved at some cost, because of the need to customize drilling equipment and place the slab-on-grade after installation of the loops is complete.

A detailed quantitative evaluation of alternatives for installing the geothermal technology requires a treatment of alternatives; (i) using low clearance drilling equipment so that drilling is taken off the critical path as the base case. (ii) Adopting a 'zoned' excavation so that drilling (using conventional drilling rig) can overlap with excavation (with a construction platform) as the innovation. The relevant tools for evaluation are: (i) 3D and 4D models to analyze issues of congestion for the second alternative; (ii) master schedules and micro-schedules to assess detail schedule savings and (iii) costs and cash flow models to analyze project revenues and financing costs.

4.3.6 Evaluation of Prefabricated Re-enforcement

The practice of using loose bar reinforcement is predominant in the building industry. Prefabricated re-bar can be factory made, fabricated off-site or on-site (depends on site conditions) and comes in three forms: i) factory made fabric reinforcement fabricated in accordance with design codes to match commonly used loose bar configurations engineered for particular use; ii) a combination of fabric reinforcement and cut and bent loose bars prefabricated into mats and cages prior to fixing; and iii) cut and bent loose bars fabricated into mats, cages etc. by welds or tied. Fabrication by welding can be done manually or by the use of machines. The welds are formed through electrical resistance welding or electric arc welding based on code requirements.

Prefabricated re-bar has significant schedule and cost benefits for the project, especially given concerns about the availability of skilled rebar tradesmen.

The tonnage fixed per man-day can be up to nine (9) times that for loose bars (Bennett, MacDonald, & British Cement Association, 1992). It therefore leads to reduced floor cycle times and enhances the construction schedule. The time savings could readily justify the extra cost of off-site fabrication. The major benefit is to optimize the use of scarce experienced re-bar crew at the work face.

The method can be combined effectively with the raised construction platform concept for temporary staging and storage before hoisting in place. Variations in fixing cost are significantly less with prefabricated re-bar (quotations for fixing re-bar varies according to the bar size, length, access, degree of difficulty, reinforcement congestion and fixtures). Other benefits include planned delivery of fabricated units, uniform workload, less congestion at the workface and better access. Use of prefabricated re-bar requires commitment and collaboration between the developer, the construction manager, designer, re-bar trades and fabricators. The economies of cost and time will be realized with repetition; a minimum of 20 units for any set of prefabrication is recommended (Bennett et al., 1992).There is an exceedingly high volume of repetition of re-bar work in the project (9 - story parkade and 48 - story tower).

A detailed quantitative evaluation of this technology for the project would involve (i) analysis of typical floor cycles with micro-schedules to assess time savings; (ii) resource usage profiles to determine labor inputs for alternatives; and (iii) costs and cash flow models from time and labor savings versus material costs to analyze project economics in terms of capital costs, total costs, and net present value.

4.4 Summary of Detail Evaluation

The analytical tools viewed as being appropriate for the innovations identified are summarized in Table 4.1 (A – D). The opportunity exists to develop simplified process models that reflect the level and accuracy of information available and which provide sufficiently accurate estimates upon which to base 'go / no go' decisions for the adoption of the innovations.

Table 4.1A - Summary of Quantitative Evaluation

Innovative Methods	Tools for Quantitative Evaluation & Perspective of Evaluation	Detailed Description	List of Assumptions & Parameters	Possible Decision
Equipment Turntables	**A) Tools of Evaluation** 1) Work-zone traffic modeling. 2) Queuing theory with process simulation and delay analysis. 3) Cost Model 4) Time Model 5) Economic value and Risk model **B) Evaluation Perspective** 1) Client and Construction Manager	1) Detailed traffic observations of major streets leading to and around the project site to determine the peak and 'non-peak' times of traffic. The traffic 'data' can be used with queuing theory and process simulation to determine the optimum flow of trucks. 2) Usefulness of turntable is related to expected usage and the value of usage per unit time. The expected usage can be quantified and therefore valued as present value (PV). The capital and operation costs of the turntables can be determined as (PV). NPV can be deduced. 3) Using traffic modeling, queuing theory and delay analysis a risk model can be developed to determine the probability of time savings from turntable versus delays in traffic.	1) Efficiency & performance of concrete pump and jump elevators depends on the Turntables. 2) Volume of material and concrete deliveries (through jump elevators and concrete pumps) can be determined from project details. **Parameters** Increment in NPV and time savings	1) Positive and significant increment in NPV to support the use of construction turntables. 2) Probability of real time savings must be significant (e.g. 80% or higher).

Table 4.1B- Summary of Quantitative Evaluation

Innovative Methods	Tools for Quantitative Evaluation & Perspective of Evaluation	Detailed Description	List of Assumptions & Parameters	Possible Decision
Jump Elevators	**A) Tools of Evaluation** 1) Cost model. 2) Time model **B) Evaluation Perspective** 1) Client and Construction Manager	1) Savings in 'idle' time (movement) for jump elevators dedicated to personnel and materials can be estimated and valued. Cost of installing and operating jump elevators would be capitalized as present values. 2) Convert savings in idle time converted into micro-schedule savings of work packages serviced by jump elevators. Aggregate micro-schedule savings into shortening of project duration. Evaluate benefits of reduced project duration in terms early revenues and savings in financing cost of project. Capitalize benefits and costs through NPV.	1) Separate and dedicated elevators to different categories of materials, work packages and personnel. 2) Realistic values of idle time within the project context. **Parameter** Increment in NPV and Time Savings	1) Positive and significant increment in NPV to support the use of jump elevators. 2) Significant and certain contribution to time (schedule) savings.
Construction Platforms	**A) Tools of Evaluation** 1) Cost model. 2) Time model 3) Risk model 4) Process Simulation for alternatives based on standard industry outputs and production rates. 5) 3D and 4D models for analysis of state of the site at different points in time **B) Evaluation Perspective** 1) Client and Construction Manager	1) Compares benefits with total and incremental capital cost of innovation. 2) Increment in Net Present Values considering revenues and savings in financing cost due to innovation. 3) Time savings. 4) Risk of achieving cost and time savings. 5) Innovation should result in project acceleration.	1) Being ready for the Olympics is the benchmark for assessing time savings. 2) Alternatives are not affected by shoring cost. 3) Balanced production in excavation and removal.	1) NPV of innovation must exceed that of conventional method. 2) Duration of excavation for innovation must be less than that of conventional. 3) High probability of achieving increment in NPV and time savings.

Table 4.1C - Summary of Quantitative Evaluation

Innovative Methods	Tools for Quantitative Evaluation & Perspective of Evaluation	Detailed Description	List of Assumptions & Parameters	Possible Decision
Vertical Closed Loop System	**<u>A) Tools of Evaluation</u>** 1) Cost model. 2) Time model 3) Risk model 4) Process simulation for alternatives based on standard industry outputs and production rates. 5) 3D and 4D models for analysis of state of the site different points in time **<u>B) Evaluation Perspective</u>** 1) Client and Construction Manager	1) Requires treatment of alternatives; (i) using low clearance drilling equipment so that drilling is taken off the critical path as the base case. (ii) adopting a 'zoned' excavation so that drilling (using conventional drilling rig) can overlap with excavation (with a construction platform) as the innovation. 2) Compares savings in capital cost using conventional approach versus tradeoffs between time and cost using customized rig. 3) Schedule analysis, 3D & 4D models and a risk model will provide a level of certainty in the estimates made.	1) It is assumed that the completion of at most two zones would provide enough space to for a drilling rig to operate while excavation continues. 2) When space constraints permit, two drilling rigs can be used to speed up the drilling process. 3) After substantial drilling activity, a single drilling rig can be used. This will make room for the substructure work while drilling for the geothermal system is completed. **<u>Parameter</u>** Increment in NPV and time savings	1) Given that the difference in cost of low clearance drilling equipment and the normal equipment is established. The discounted cost of schedule extension due to the innovation should be significantly less that the difference in capital cost.

Table 4.1D - Summary of Quantitative Evaluation

Innovative Methods	Tools for Quantitative Evaluation & Perspective of Evaluation	Detailed Description	List of Assumptions & Parameters	Possible Decision
Concrete Placement Technologies	**A) Tools of Evaluation** 1) Cost model. 2) Time model 3) Risk model 4) Process simulation for alternatives based on standard industry outputs and production rates. **B) Evaluation Perspective** 1) Client and Construction Manager	1) Compares benefits with total and incremental capital cost of innovation. 2) Determine increment in NPV considering revenues, savings in financing cost due to innovation and cost of innovation. 3) Time savings from innovation. 4) Certainty in cost and time savings.	1) The influence of floor cycle times on other activities is the same for both methods i.e. follow up work can match superstructure cycle times. 2) The concrete placement component of the two alternatives is distinctively separate and can be estimated based on: i) the capacity and output of each system ii) analysis of micro-schedule for floor cycles iii) process simulation to confirm time savings of each method. 3) Uniform or equal floor cycle times is considered for tower construction. **Parameter** Increment in NPV and time savings	1) NPV of innovation must exceed that of conventional method. 2) Floor cycle times must be significantly less than that of conventional. 3) High probability of acceleration from the innovation
Prefabricated Reinforcement	**A) Tools of Evaluation** 1) Input resource analysis for labour. 2) Master schedule for tower construction and micro-schedule for typical tower floor to analyze schedule savings of alternatives. 3) Costs models assess cost of inputs against benefits. **B) Evaluation Perspective** 1) Client and Construction Manager	1) Assess cost savings in labor and schedule of innovation. 2) Compare benefits with total and incremental capital cost of innovation. 3) Determine increment in NPV considering revenues and savings in financing cost 4) Determine certainty in cost and time savings. 5) Innovation should result in project acceleration.	1) Assume the same quantity of re-bar for base case and innovation. 2) No delivery or availability problems for either method. 3) Other trades (mechanical/electrical) are not affected by either method.	1) NPV of innovation must exceed that of conventional method. 2) High probability of acceleration from the innovation

CHAPTER 5

5.1 Conclusion

Increasing complexity of AEC projects, rising costs and competition has engendered the need for innovative design and construction technologies. At the project level there are always questions of costs, benefits and risks (mostly without a structured format) when new or known but 'unused' technologies are to be introduced. Clearly project organizations need a tool to assist in the evaluation of the objective and subjective costs and benefits of innovative technologies.

The objective of the thesis has been to test an existing screening framework, which captures a wide range of criteria, by exploring a number of innovative construction methods in the context of an actual building project. The thesis being part of an ongoing research project dealing with the development of an evaluation framework, it thus, examines the use of the framework on a case study and determines the needs for a quantitative dimension. As a useful generic framework, the broad category of filters (major criteria) is largely the same for both material/component innovation and process innovations. In terms of details the (AboMoslim & Russell, 2005) framework emphasized factors related to the performance and structural quality of materials and components notably, sound properties, fire properties, durability, materials and system designs. Factors that were introduced to facilitate the evaluation of process innovations include; technology or methods interaction, congestion, procurement lead times and environmental effects. This reiterates the notion that there can be no 'one-size-fits-all framework' for evaluating construction innovations. There will be differences depending on the type of innovation (material/component systems, procurement systems, sustainable systems, methods and process innovations).

To introduce flexibility at the preliminary screening stage, a scoring system was developed for sub-factors of the major criteria (filter). Tables 3.5 (A – I) chapter 3, gives positive (+ve) and negative (-ve) scoring system for each sub-criteria that enhances or inhibits a particular filter.

Unlike the existing framework that is based on predetermined sub-factors for a single innovation, the flexibility added enhances the treatment of applicable and practical sub-factors of multiple innovations. It facilitates a thorough screening of multiple innovations and the possibility of developing approximate formulations (from the positive (+ve) and negative (-ve) scoring).

In applying the framework it was further observed that there is the need to clearly define what constitutes a stakeholder acceptance, because some stakeholders will either accept or decline an innovation based on other criteria (e.g. cost, time etc.) that in turn serve as another filter. In such instance it is not clear on which screen (criteria) the technology fails.

The framework was applied to a project which has a considerable number of constraints and varied project stakeholders: Developer, Construction Managers, Consultants, Vancouver City Authorities and Heritage Commission (Regulatory Authorities), Sub-contractors, Adjoining businesses (neighbors), etc. The application not only highlights features of the technologies and evaluation framework, it also provides insight into the perception and attitudes of various stakeholders towards innovative methods. This indicates the conflicting objectives of various project stakeholders and the risks and challenges of adopting innovative technologies.

The thesis sought to establish the relevance of evaluation schemes and the introduction of significant innovations and efficiencies in AEC projects. The analysis gives positive indications that there are significant benefits to be gained if evaluation schemes are fully integrated into the early planning stage of projects. This is supported by the Construction Managers' intended adoption of a number of the screened technologies. These include: 1) Construction Platforms for deep excavation, 2) Concrete Placement system for high-rise and 3) Prefabricated Re-bar. Although they form a minority in relation to the number of technologies identified and screened, their very adoption supports the need for such evaluation schemes. Evaluation schemes has often been perceived by most practitioners in the AEC industry as reserved for the large and complex projects involving ground breaking or complex technologies. However, it can be deduced from the thesis that appropriate evaluation frameworks for 'average sized' projects can result in positive gains and improved engineering and managerial judgment on projects.

A comprehensive literature review was conducted in respect of the state of the art in terms of quantitative evaluation / assessment methods.

There is a limited but growing literature that delves in theoretical quantitative evaluation of innovative design and construction technologies. The apparent lack of information on practical quantitative tools on actual AEC projects can be attributed to the short planning cycle of most projects that does not permit detailed and documented evaluation schemes.

5.2 Recommendation

Further research is required for preliminary screening procedure of (AboMoslim & Russell, 2005), in terms of developing an appropriate scoring system and to make it more objective.

Future study is required for the full development of the quantitative framework initiated in this thesis. A broadening of the literature review is required to examine other screening/evaluation schema used in allied industries and how concepts can be appropriated for the construction industry. Continuing interaction with industry through case study projects will facilitate refinement of the framework, full assessment of innovations, feedback from industry participants, and hence validation of the framework.

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APPENDICES

Appendix A – Summary of Presentation to Scott Canada Limited

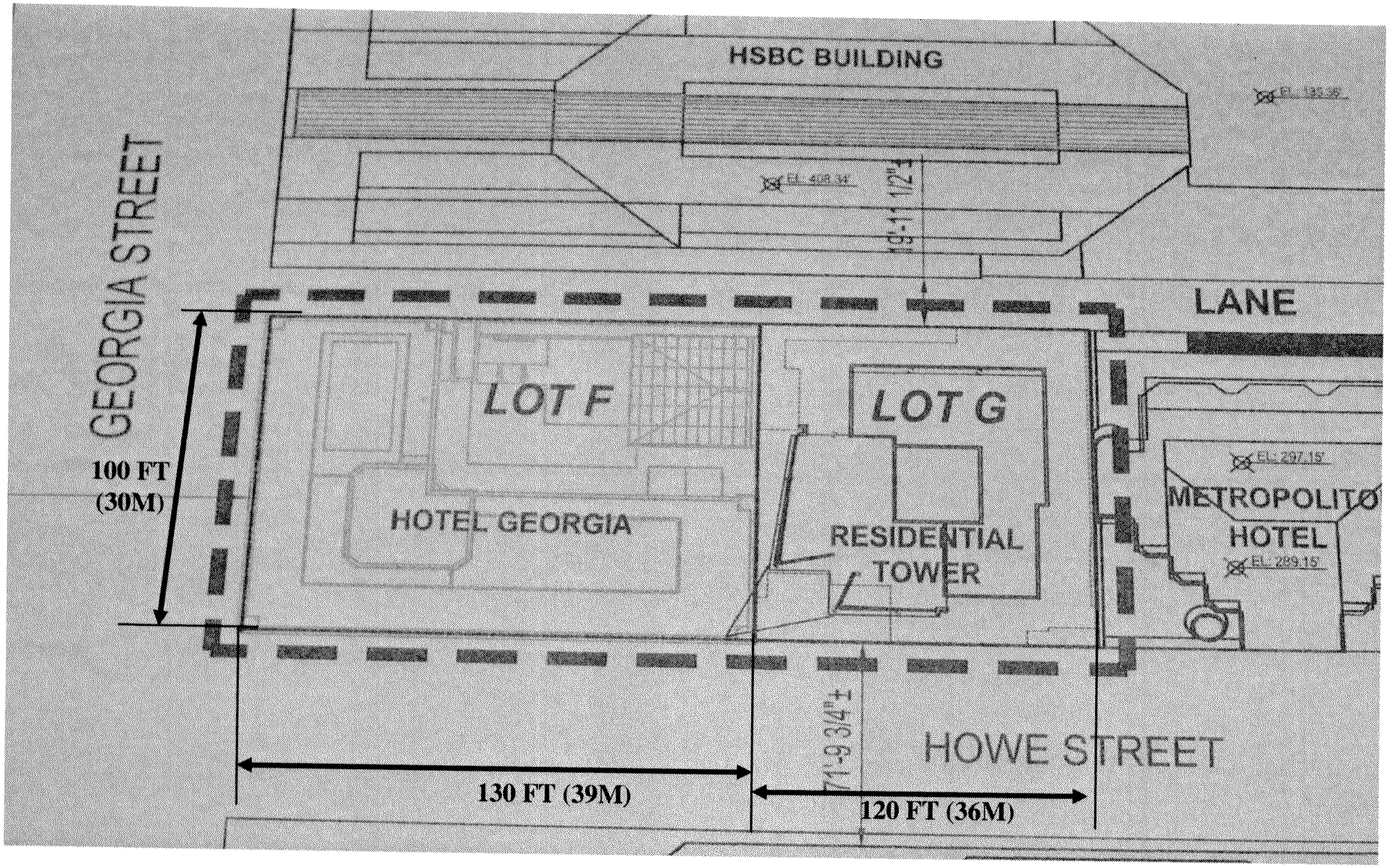
PROPOSED CONSTRUCTION METHOD	MAJOR FACTORS	APPLICABILITY
1)Up / Down Construction	1) Reduce overall Project Schedule and eliminates the problem of substructure construction in inclement weather **(+ve)** 2) Eliminates problem of easement rights for shoring and underpinning **(+ve)** 3) Unsuitable Geotechnical conditions **(-ve)** 4) The technology has never been used in Vancouver - High risk involved **(-ve)**	Not Applicable
2)Geothermal Technology – (Horizontal Bored Closed Loop System)	1) Reduced cost of drilling which can be done as a non-critical activity **(+ve).** 2) Minimal effect on site congestion and no interference with other technologies **(+ve)** 3) Limited space (horizontal tract) to meet thermal capacity **(-ve).** 4) Underground service lines beyond the property line. **(-ve)** 5) Performance is susceptible to seasonal climatic changes. **(-ve)**	Not Applicable
3)Geothermal Technology – (Vertical Closed Loop System)	1) Site Conditions and basement configurations makes this option most suitable **(+ve).** 2) Use of low clearance equipment can result in a positive impact on schedule **(+ve).** 3) Eliminates the problem of easement rights from adjoining properties **(+ve).** 4) High cost of drilling with some geotechnical risk **(-ve).**	**Applicable.**
4) Turntable for Equipment and Trucks.	1) System for faster and efficient delivery/removal of materials in a restricted site. **(+ve)** 2) Combine effectively with other technologies. **(+ve)** 3) Needs to be customized for peculiar site conditions **(-ve).** 4) Technology not readily available in North America. **(-ve)**	**Highly Applicable**

APPENDICES

Appendix A – Summary of Presentation to Scott Canada Limited

PROPOSED CONSTRUCTION METHOD	MAJOR FACTORS	APPLICABILITY
5) Construction Platforms – Elevated & Grade Level	1) Grade level platform will enhance the deep excavation works without ramps **(+ve).** 2) The raised platform will facilitate controlled and speedy delivery of materials; reduce queuing, congestion and turnaround times (+ve) 3) Raised platform will be useful in providing temporary staging area. 4) Simple technology that can be designed and fabricated to suit the project **(+ve)**	**Highly Applicable**
6)Self Compacting Concrete SCC	1) Increased rate of placement of concrete and reduced floor cycle times and enhanced project schedule **(+ve).** 2) Eliminates vibration and reduces noise in concrete placement and allows concrete placement at early and late hours **(+ve).** 3) Does not require special equipment and local companies can supply SCC **(+ve).** 4) Very costly which cannot be offset by the elimination of vibration **(-ve).**	Fairly Applicable
7)Offsite Prefabricated Re-inforcement	1) Increases the rate of placement re-bar much faster than the conventional method of fixing loose bars at the workface. Reduced 'floor cycle times' and enhanced project schedule **(+ve).** 2) Reduces the effect of the shortage of skilled labor for re-bar works. 3)	**Highly Applicable**
8)Concrete Handling,- Trailer Pump, Pressure pipe and Stationary Boom	1) Efficient Method of moving concrete in a restricted site for the construction of the tower. **(+ve)** 2) Combines effectively with other technologies, E.g. Turntables. **(+ve)** 3) Equipment available in North America (U.S.) **(+ve)**	**Highly Applicable**

Appendix B – Details Of Case Study Project



Appendix B – Details Of Case Study Project
Pictorial Details of the Site of Hotel Georgia

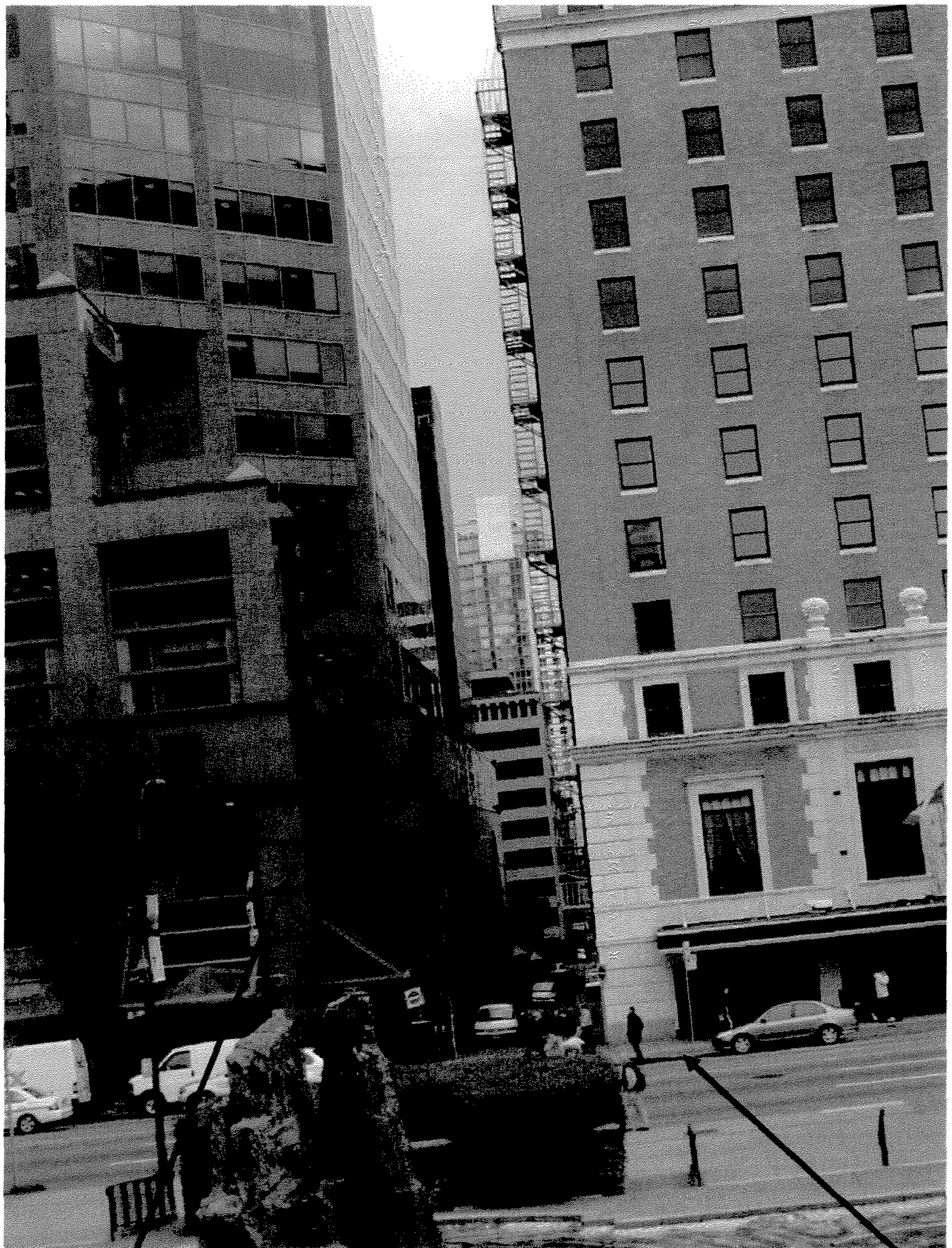
Existing Hotel Georgia – Internal details will be gutted and renovated while keeping the external envelope intact due to heritage requirements

Adjacent Metropolitan Hotel with 'exterior brick facing.' Proposed Tower will 'butt' this structure from P8 (underground) to Level 18

Daytime vehicular traffic in the vicinity of case study project.

Appendix B – Details Of Case Study Project

Pictorial details of main access to the 'Site' of Hotel Georgia



HSBC Tower adjacent to Hotel Georgia.

20 foot Lane that will act as a major access and point of delivery and temporary staging for the project.

Appendix B – Details Of Case Study Project
Pictorial details of main access to the 'Site' of Hotel Georgia

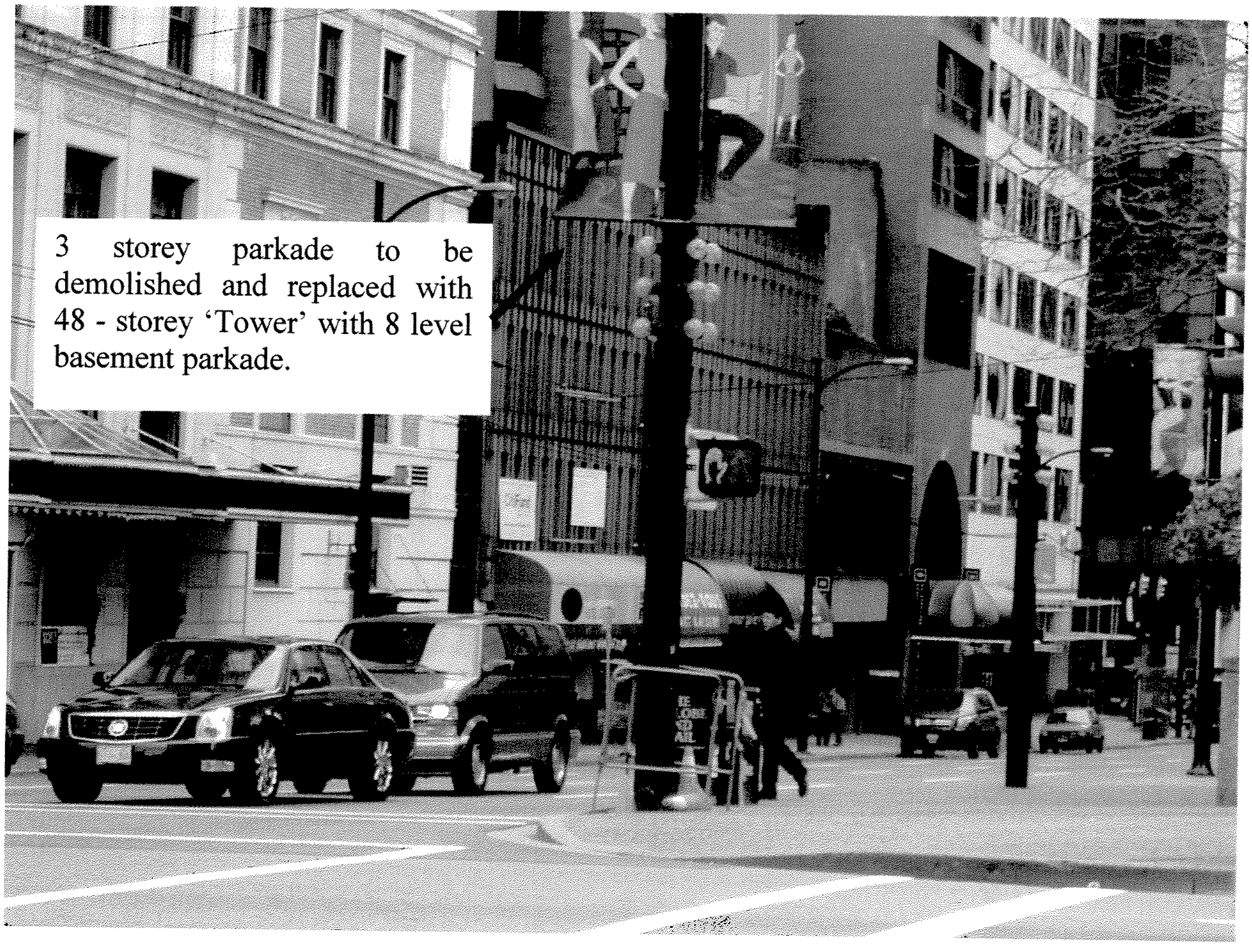
Metropolitan Hotel

HSBC Tower.

3 storey parkade to be demolished and replaced with 48 - storey 'Tower' with 8 level basement parkade.

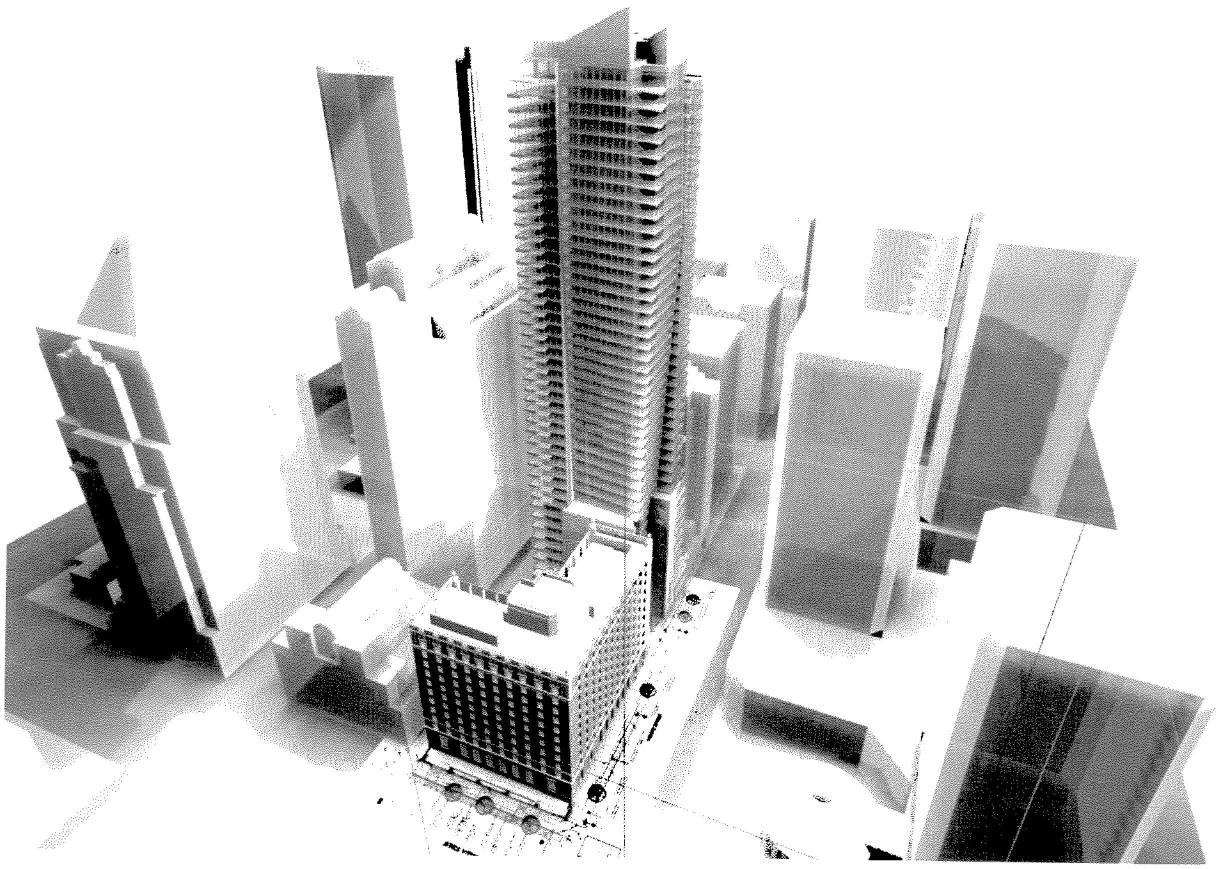
20 foot Lane that will act as a major access and point of delivery and temporary staging for the project.

Appendix B – Details Of Case Study Project
Pictorial details of Hotel Georgia and Howe Street

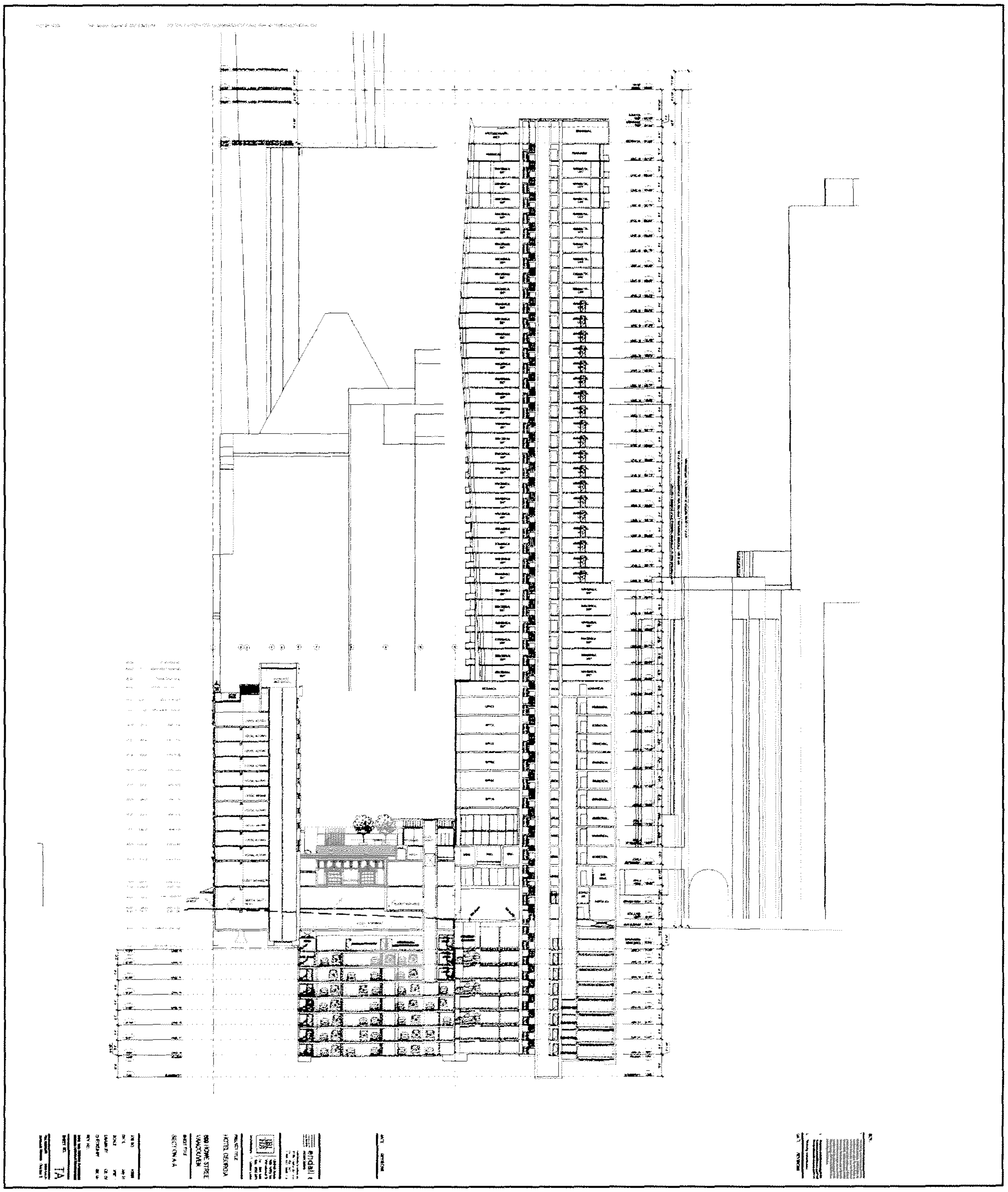


Appendix B – Details Of Case Study Project

Architectural 'Model' of the proposed Tower and Hotel Georgia



Appendix B – Details Of Case Study Project
Architectural Section of Proposed Tower for Hotel Georgia



Appendix C

Illustrative Details of Stages in Up/Down Construction

SOURCE - Skyline Steel, LLC, 8 Woodhollow Road, Parsippany, NJ 07054
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Stage 1: Sheet pile installation
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Stage 2: Concurrent pile foundation installation
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Stage 3: Base slab construction
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Stage 4: Access for below grade excavation
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Stage 5: Below grade excavation in progress
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Stage 6: Finished Basement Parking Structure
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Site footprint of early foundation construction concurrently with basement structure
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Concurrent 'tower' and 'below grade' construction
See web image at the following address:
http://www.skylinesteel.com/assets/Bulletins/TopDownHybrid_TB.pdf

Appendix D
Illustrative Details of Geothermal Heat Pump (GHP) Technology
Source: Virginia Department of Mines, Minerals and Energy
and U.S. Department of Energy (USDOE)
www.geo4va.vt.edu/A3/A3.htm.

1) Typical Diagram of a Hybrid GHP System.
See web image at the following address:
http://www.geo4va.vt.edu/A2/GHP-w-cooling-tower-wHX.gif

2) Horizontal ground loop diagrams, showing parallel arrangement of loops.
See web image at the following address:
http://www.geo4va.vt.edu/A2/GHP-w-cooling-tower-wHX.gif

3) Vertical Ground Loop Diagram
See web image at the following address:
http://www.geo4va.vt.edu/A2/loop-vertical.gif

4) Feeding U-tube element from spool into borehole. A temporary casing prevents borehole well collapse and is removed after element is in place.
See web image at the following address:
http://www.geo4va.vt.edu/A2/feeding-u-tube.jpg

5) Equipment for drilling vertical boreholes. U – tube elements have been fed into the first two boreholes and casing has been removed from first one (foreground).
See web image at the following address:
http://www.geo4va.vt.edu/A2/drill-rig+u-tubes.jpg

Appendix E
Illustrative Details of Beeche Exterior Cladding System for High-rise Buildings

Source: www.beeche.com , www.CIF.org and Tommelein and Beeche (2001)

1) The Curtain Wall Panels are stored on a Material Handling Grid below the Aluminum Space Frame System until they are hoisted into position on the Building
See web image at the following address:
http://cic.vtt.fi/lean/singapore/Tommelein&BeecheFinal.pdf

2) The 'Crab' is a versatile yet relatively small 'roof crane. It is positioned with 15 – Storey intervals to hoist the panels from the space frame up to elevation using the cable guide system.
See web image at the following address:
http://cic.vtt.fi/lean/singapore/Tommelein&BeecheFinal.pdf

3) Hoisting Carriage and cable – guide system.
See web image at the following address:
http://cic.vtt.fi/lean/singapore/Tommelein&BeecheFinal.pdf

4) Walking a panel on the transverse system for installation.
See web image at the following address:
http://cic.vtt.fi/lean/singapore/Tommelein&BeecheFinal.pdf

5) Fig. 5 – Monorail system is clamped onto building columns. It is located below the 'Crab' level and consists of continuous tubular wrapping around the entire building with trolleys (blue color) suspended from it. It allows panels to be swung away from corners.
See web image at the following address:
http://cic.vtt.fi/lean/singapore/Tommelein&BeecheFinal.pdf

6) Panel Suspended from trolley on a monorail system ready for final installation
See web image at the following address:
http://cic.vtt.fi/lean/singapore/Tommelein&BeecheFinal.pdf

Appendix F
Illustrative Details of Construction Turntables

1) Equipment Turntable - Pit mounted turntable includes a 'pit – ring' that protects the concrete curb surface and adds support to the edge of the turntable when driven on.
Installation
See web image at the following address:
http://www.solvinginc.com/images/turn%20table%20in%20floor.jpg

2) Surface mounted 'rail turntable' for trucks. This can be used by haulage trucks.
Source: Maschinen- und Stahlbau Dresden, Niederlassung der Herrenknecht AG
Hofmühlenstraße 5-15, 01187 Dresden, Germany
www.msd-dresden.de
See web image at the following address:
http://www.msd-dresden.de/img/Fotos/33-3.jpg

3) Construction Turntables, Outside Diameter: 10-60m
Load Capability: 10-150t
Device weight: 8-120t
Rotary Speed: 30-240min/r
Power: 0.55-2.2Kw
Level: Less than 5mm
Circularity: Less than 5mm Equipment Turntable
See web image at the following address:
http://www.360platform.com/sitebuilder/images/pit-drive012-344x253.jpg

Appendix G
Illustrative Details of Construction Platforms

See web image at the following address:
http://cee.engr.ucdavis.edu/faculty/boulanger/geo_photo_album/Retaining%20structures/Century%20Hotel/Century%20Hotel%20P6-Labeled.jpg

Appendix H
Illustrative Details of Concrete Pumping and Placing Equipment for High – rise Buildings.

1) McHugh Construction Putzmeister BSA 14000 (630 horse power engine) pumps an average of 100 cu yds per hour from the basement of Trump Towers Chicago.

See web image at the following address:

http://www.putzmeister.com/data/sr/DSC_0013_ALR.jpg

2) The series II detach boom is attached to the core of the Trump Tower Chicago.

See web image at the following address:

http://www.putzmeister.com/data/sr/DSC_0013_ALR.jpg