Proposal

PricewaterhouseCoopers
Oslo, Norway

James Wilson
Structural Option
AE 481W Senior Thesis
The Pennsylvania State University
Faculty Consultant: Professor M. Kevin Parfitt

Table of Contents

Executive Summary

In 2003 *Oslo S Utvikling* hosted an international architecture competition for the lot located south of the *Oslo S* train lines - between the outrun of *Akerselven* and *Middeladerparken*. The competition was jointly won by *MVRDV*, *Dark Arkitekter*, and *A-lab* with their proposal for the *Barcode* development. The new *PricewaterhouseCoopers* (PwC) building is the first building to be completed in the *Barcode* strip and will be “the face” of the *Barcode* towards the west. The 12 story superstructure consists of precast concrete decking on a steel frame with cast in place shear walls at the core. The substructure is comprised of cast in place concrete and extends two stories below grade.

Studies conducted on the existing conditions (Technical Report 1, 2, 3) determined that the existing structural system is optimal for the location of Oslo, Norway. However, if the entire BARCODE development were hypothetically moved to Dorchester Avenue, Boston, MA, it is likely that design and construction methods of the PwC building would be different due to local labor expertise, codes, design loads, geographic differences etc. This thesis will study how design and construction aspects change due to change in location.

Technical report 2 determined composite steel decking to be a good alternative to the existing gravity system. It shares many of the desirable qualities of the existing structure, while potentially being more economical due to local labor expertise of Boston, MA. Therefore a redesign of the gravity will be conducted to consist of composite decking on a steel frame. A change in gravity system, consequently incurs a redesign of the lateral system. Alterations to construction cost, scheduling, and architecture, will also be addressed in this thesis.

1 – Existing Conditions

1.1 Architecture

In 2003 *Oslo S Utvikling* hosted an international architecture competition for the lot located south of the *Oslo S* train lines - between the outrun of *Akerselven* and *Middeladerparken*. The competition was jointly won by *MVRDV*, *Dark Arkitekter*, and *A-lab* with their proposal for the *Barcode* development. The new *PricewaterhouseCoopers* (PwC) building is the first building to be completed in the *Barcode* strip and will be "the face" of the *Barcode* towards the west. The *Barcode* concept is based on a series of eight to ten buildings, each with their own individual form and character. The intention is to provide unique multifunctional architecture with a lot of light, variation and accessibility.

Figure 1: Barcode Concept

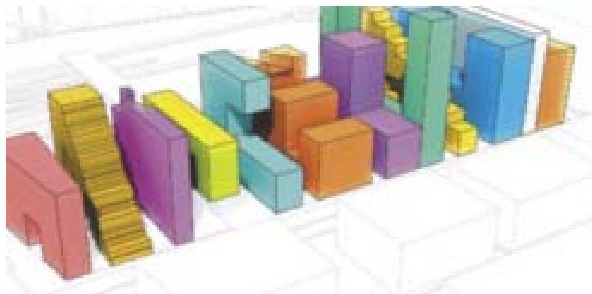

Figure 2: Image Barcode Concept

- *Images courtesy of Oslo S Utvikling*

The exterior shape of the PwC building is simple and defined. The east side runs perpendicular to *Nydalen Alle* and the west side follows the property line, creating a rhombus like shape in plan. There are of two stories below grade and twelve above grade with a five story opening in the center of the façade indicating the main entrance. The building envelope consists of curtainwall glazing, metal paneling and tar paper roof, intended to give off an impression of lightness, openness and technological sophistication. The story height is 12 ft which will be similar for all the buildings in the *Barcode* development.

The program inside mainly conforms to the needs of the professional services firm, PricewaterhouseCoopers. Technical rooms and parking are located on sub grade floors. The first three floors above grade contain an auditorium, a reception area, meeting rooms, and towards *Nydalen Alle*, shops and display rooms. The forth through the eleventh floors hold conference and office spaces. A grand cafeteria with spectacular views and outdoor dining options is located on the top floor. The core consists of a permanent technical zone that contains communication, technical installations and wet services, in addition to zones that can be designed differently depending on the need of the different departments.

1.2 Drawings

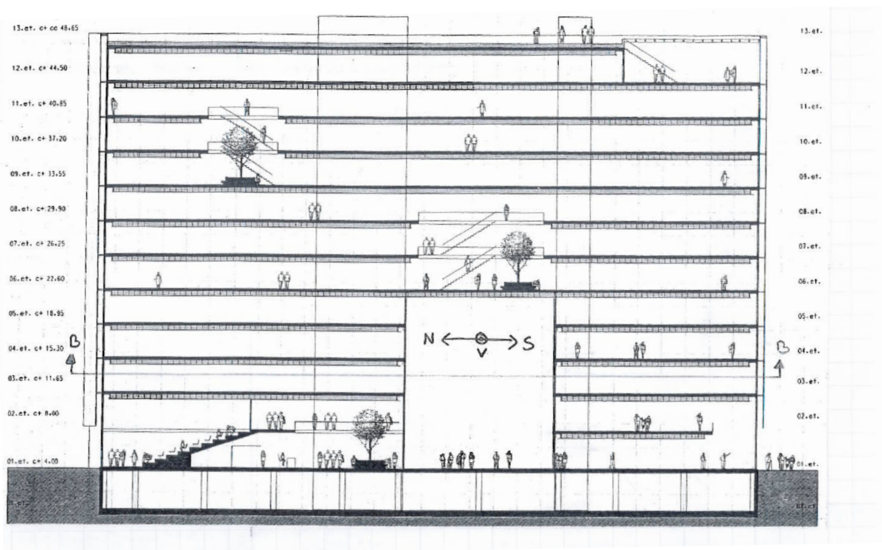

Figure 3: Building Section

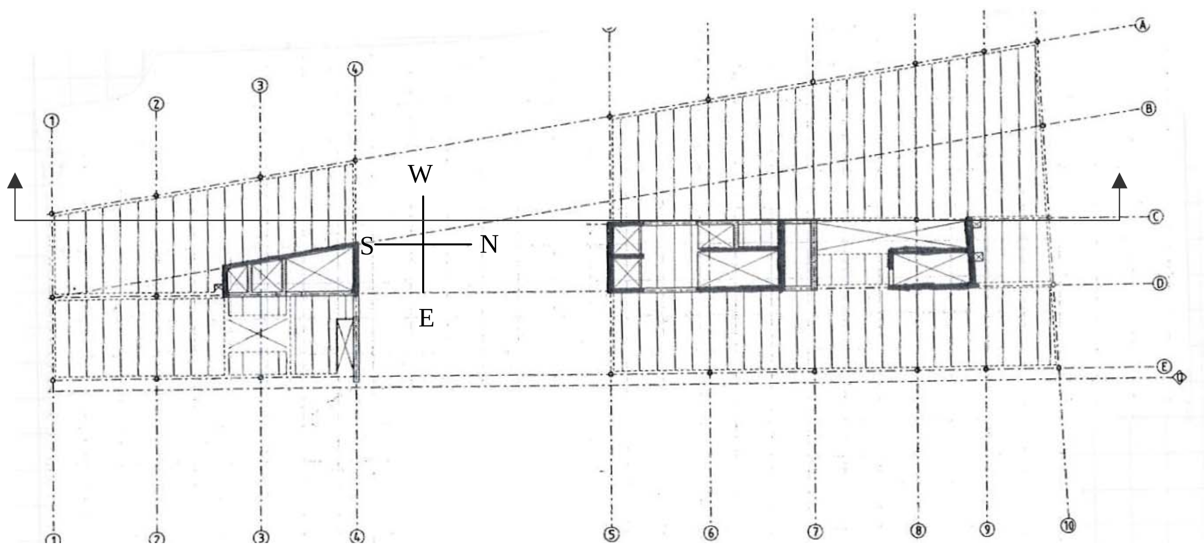

Figure 4: Typical framing plan for floors 1 – 4

1.3 Gravity System Discussion

The superstructure of the building consists of precast concrete decking on a steel frame with cast in place shear walls at the core. The decking is prestressed hollow core concrete plank with typical sections of 120cmx30cm and spans ranging from 10 to 20 meters. Along the interior of the building, planks typically rest on steel angles fastened to the concrete core (figure 6). Along the exterior, planks typically rest on the bottom flange of a special steel beam (HSQ profile, figure 5). The beams are fabricated by precast engineer and conceal the flange and web within the plane of the slab, creating extremely low structural depth. The beams are supported by circular hollow structural steel columns filled with reinforced concrete. The opening at the center of the façade is allowed through three trusses comprised of hollow circular steel tubing for diagonal/vertical members and HSQ beams for horizontal members.

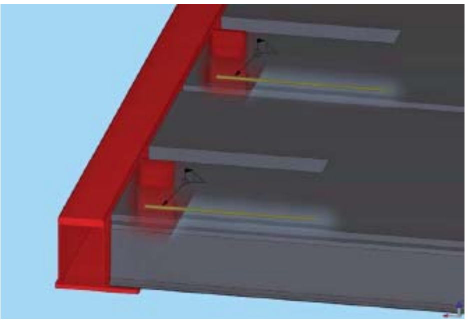

Figure 5: Principle connection of deck elements with one sided HSQ steel beam.

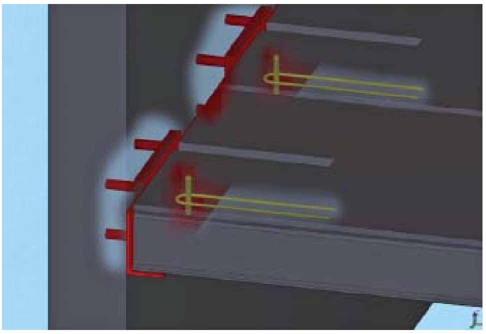

Figure 6: Principle connection of deck elements with interior concrete shear wall.

-images courtesy of Norsk Stålforbund and Betongelement Foreningen

There are two stories below grade comprised of cast in place concrete. The lowest level has a slab thickness of 500mm with recessed areas for elevator shafts. The other floor slabs below grade are 300mm thick, with exception of areas below outdoors where slab thickness is increased to 400mm.

1.4 Lateral System Discussion

Lateral resistance is provided by cast in place concrete shear walls located at the center of each leg of the building. Concrete plank decking acts as a rigid diaphragm that transfers loads to the shear walls. The building is tall and narrow in the short direction and therefore requires thick shear walls. Walls are typically 400mm thick in the short direction and 300mm in the long direction.

The narrow building shape also causes large overturning moments. Cores are integrated into the cast in place concrete substructure and acts as a base to distribute the overturning moments to the foundation. The foundation uses steel and concrete piles to transfer axial tension, axial compression and lateral loads to the ground. Piles are driven between 100 and 130ft to bedrock.

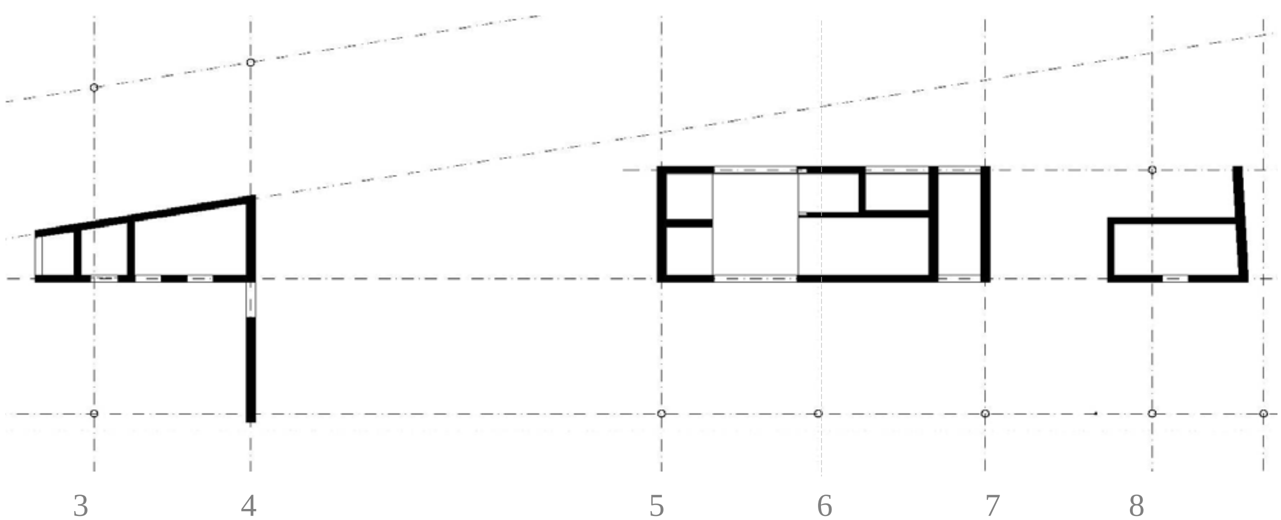

Figure 7: Typical Shear wall layout

2 – Proposal

2.1 Problem Statement

Studies conducted on the existing conditions (Technical Report 1, 2, 3) determined that the existing structural system is optimal for the location of Oslo, Norway. However, if the entire BARCODE development (1.1 Existing Conditions) were hypothetically moved to Dorchester Avenue, Boston, MA, it is likely that design and construction methods of the PwC building would be different due to local labor expertise, codes, design loads, geographic differences etc. This thesis will study how design and construction aspects change due to relocation of the site.

2.2 Site Relocation

It was decided to move the entire BARCODE development to Dorchester Avenue, Boston, MA (Figure 8-12) to keep the PwC Building in context. The design for the building relied heavily on its importance as an entity in the BARCODE as a whole. Therefore, architecturally it would not make sense to have the building as a standalone structure.

Figure 8: Site – Birds Eye View

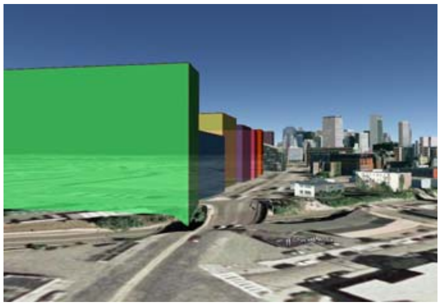

Figure 9: Site Looking North

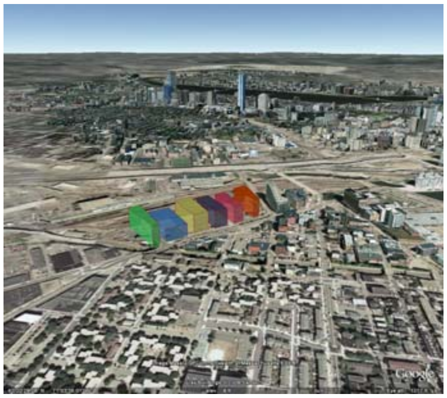

Figure 10: Site Looking West

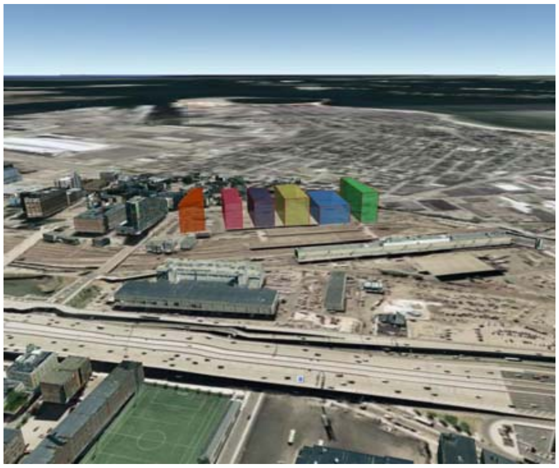

Figure 11: Site – Looking East

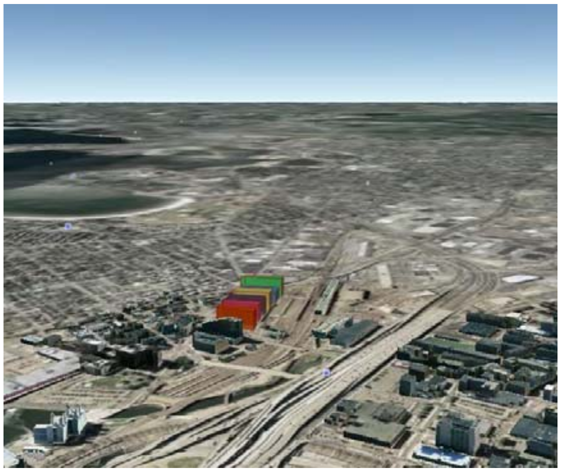

Figure 12: Site – Looking South / West

*** *Images courtesy of Google Earth***

2.3 Solution

This thesis will conduct an in depth study on composite decking on a steel frame as an alternative to the existing gravity system. A change in gravity system and design loads consequently incurs a redesign of the lateral system. Alterations to construction cost, scheduling, and architecture, will also be addressed in this thesis.

Depth Studies

Composite deck on steel frame provides as a good alternative to the existing gravity system because local labor expertise of Boston, MA potentially make this a more economical solution. Important features shared in both existing and proposed structural solutions are low structural weight on foundations and ability to provide flexible floor layout. A proposed framing layout will be determined and modeled in RAM Structural System Steel Module, from which trial members will be determined. Hand calculations will be used to verify determined results.

A redesign of the lateral system will be required due to different design loads incurred by change of site location and structural weight. Alternative steel solutions will be explored at a schematic level, however if a reasonable alternative cannot be found then a shear wall system at the core will be used. Technical report three determined that the existing lateral system experiences considerable torsion under both wind and seismic loads. The redesign will also explore methods of minimizing torsional effects, although this is not an easy task given the non-symmetrical layout. The proposed lateral system will be modeled in ETABS from which trial members can be determined.

Breadth Studies

Speed of erection is important, because the PwC building must be completed before successive buildings in the BARCODE strip can be continued. Although an all steel structure is faster to erect than an all concrete solution, it will not be as fast as the existing prefabricated structure. A comparison study will be conducted whether the savings made by change in structure are outweighed by increased construction time. Determination of cost and schedule of the new structural system will be estimated using RS Means 2007. A sequencing schedule will also conducted in Primavera. Although values obtained will not provide for direct comparison with existing conditions, it will provide an indication as to whether the proposed design can provide cost savings.

A change in the structural system will potentially incur changes to the façade and floor plans. Any alterations made to the façade will attempt to keep the existing architectural expression in tact. The goal is to keep the simple defined form and maintain an expression of transparency and technological sophistication. The importance of the PWC building as a unique entity in the BARCODE strip as a whole is also critical. The rules and regulations defined by zoning will have to be studied, such that any alterations conform within the guidelines.

2.5 MAE Requirements

As required by the MAE program, this thesis will incorporate material from a graduate level class. I have chosen to incorporate material from AE 597A – Computer Modeling of Building Structures. This will be done through modeling the steel braced frame core of the building using ETABS as structural modeling program. Below are guidelines provided by course instructor that will be followed to meet the MAE requirements.

Guidelines provided by instructor:

Develop a computer model of the lateral-force-resisting system and determine member demands due to Earthquake and/or Wind forces based on the permitted analytical procedures of the applicable building code.

The model shall represent the floor as a rigid or semi-rigid diaphragm. Structural walls and semi-rigid diaphragms shall be modeled with area elements. Beams and columns shall be modeled with line elements representing a 3-D frame element. Both the area and line elements shall account for flexural, shear, and axial deformations.

Where a 3-D building model is used with rigid floor diaphragms, a minimum of three degrees of freedom consisting of translation in two orthogonal plan directions and torsional rotation about the vertical axis shall be included at each level of the structure.

Stiffness properties of concrete and masonry elements shall consider the effects of cracked sections. For steel moment frame systems, the contribution of panel zone deformations to overall story drift shall be included.

The lateral force analysis shall consider inherent torsion, accidental torsion, and P-Delta effects. The story forces shall be distributed to the various vertical elements of the lateral-force-resisting system based on the

2.4 Tasks

Depth – Composite Deck Steel frame redesign

1. *Design Loads*
    a. Revise/confirm design loads determined in Technical Reports for location of Boston, MA.
        i. Determine gravity loads in accordance with ASCE7-05
        ii. Determine wind loads in accordance with ASCE7-05 analytical Method 2
        iii. Determine seismic loads in accordance with analytical procedure of ASCE7-05

2. *Lateral System (Meet MAE Requirement)*
    a. Schematic analysis of alternative steel lateral systems:
        1. Braced frame
        2. Staggered truss
        3. Dual: Braced frame / Concrete core
        ii. If a steel lateral system does not prove to be a viable alternative, opt with redesign of the existing shear walls to withstand new design loads.
        iii. Explore methods to decrease torsion in redesign
    b. Model design of lateral force resisting system in ETABS
        i. Determine member sizes using ETABS
    c. Spot check critical members to verify computer design
        i. Steel: AISC Manual of Steel Construction 13th Edition LRFD.
        ii. Concrete: ACI 318-08
    d. Impacts on architectural expression need to be considered for breadth study. Especially if steel braced frames are exposed.
        i. Goal: keep simple and defined building shape with light transparent expression

3. *Gravity System*
    a. Determine framing layout
    b. Model building in RAM Structural System Steel Module
        i. Design and size members using RAM
    c. Manually Spot check members to verify computer design using AISC Manual of Steel Construction 13th Edition LRFD.
    d. Design transfer girders for 5 story opening in center of East/West façade
    e. Confirm impact on foundations and spot check

4. *Construction Management – Breadth*
    a. Conduct a cost and time analysis of steel frame redesign using RS Means 2007
    b. Create a construction schedule
        i. Use of Primavera or other scheduling program

5. *Architecture – Breadth*
    a. Study zoning plan:
        i. Oslo Kommune S-4187, 16.11.2005, Regulerings bestemmelser for felt B10 i bjørvika
        ii. Oslo Kommune S-4099, 15.06.2004, Regulerings bestemmelser for Bjørvika - Bispevika - Lohaven
    b. Façade:
        iii. Formulate structural solutions that emulate architectural design goals.
    b. Discuss architectural impacts of structural steel solutions
    c. Graphically show new facades:
        i. Manipulate existing images in Photoshop
        ii. Model building envelope in Sketchup in order to graphically show changes.
    c. Floor Plans
        iii. Redesign of the core due to relocation of lateral force resisting elements
        iv. Attempt to minimize significant change in architectural floor plans

2.5 Schedule

Depth	*Jan 12 - 16*	*Jan. 19 -23*	*Jan. 26 - 30*	*Feb. 2 - 8*	*Feb. 9 - 13*	*Feb. 16 - 20*	*Feb. 23 - 27*	*Mar. 2 – 6*	*Mar. 9- 13*	*Mar. 16 - 20*	*Mar. 23 - 27*	*Mar. 30 – Apr. 3*	*Apr. 6 – 10*	*Apr. 13 – 17*
Revise Proposal														
Research steel braced frames														
Schematic Design														
Revise Design Loads														
Model Lateral System Alternatives														
Evaluate alternatives														
Determine Member Sizes														
Become familiar with RAM														
Model Gravity system														
Determine member sizes														
Confirm impacts on foundations									*Spring break*					*Present Tues Apr. 14th at 2.40pm*
Collect Documentation														
CM Breadth														
Material takeoffs														
Schedule														
Architecture breadth														
Location of BF														
Produce graphics														
Compile and write paper														
Milestones		26th Jan.		9th Feb.		23rd Feb.			16th Mar.					

2.6 Conclusion

The following semesters work will focus on hypothetically moving the PWC building to Dorchester Avenue, Boston, MA, and the consequent changes involved in its design and construction. The structural gravity system will be redesigned to utilize a composite decking on a steel frame opposed to the existing prefabricated system. A redesign of the lateral system will be required due to different design loads incurred by change of site location and structural weight. Alterations to construction cost, scheduling, and architecture due to the new structural system, will also be addressed.