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Innovation in Construction Techniques for Tall Buildings
– Aerodynamic Advancement of the Lifting Wing

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INNOVATION IN CONSTRUCTION TECHNIQUES FOR TALL BUILDINGS
– AERODYNAMIC ADVANCEMENT OF THE LIFTING WING

By
Ian R Skelton

A dissertation thesis submitted in partial fulfilment of the requirements for the award of the degree Doctor of Engineering (EngD), at Loughborough University

May 2014

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Regents Place
London
NW1 3BF

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Department of Civil & Building Engineering
Loughborough University
Loughborough
Leicestershire, LE11 3TU
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The ever-enthusiastic tall building specialists who travel the world chasing the tallest towers and complete carefully considered responses to probing questionnaires and interviews.
Finally, special thanks to:
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Max and Sam Skelton for providing brief periods of quiet and calm, allowing me to focus the attention, whilst they grew from babies to toddlers to ‘big boys’;
Mum and Dad for the gentle prods and pokes along the way;
Grandpa Bob for his searching weekly questions like “haven’t you finished it yet E?” – Finally, Yes!
ABSTRACT

Tall Buildings Are Here To Stay - Historical Précis

The skyline of many ‘world cities’ are defined and punctuated by tall buildings. The drivers for such dominant skylines range from land scarcity and social needs; high real estate values; commercial opportunity and corporate demand, through to metropolitan signposting. This fascination with tall buildings started with the patrician families who created the 11th Century skyline of San Gimignano by building seventy tower-houses (some up to 50m tall) as symbols of their wealth and power. This was most famously followed in the late 19th Century with the Manhattan skyline, then Dubai building the world’s highest building, then China building some eighty tall buildings completed in the last 5 years, then UK building Europe’s highest tower, the Shard and finally back to Dubai, planning a kilometre tall tower, potentially realising Ludwig Mies van der Rohe’s ‘Impossible Dream’ of the 1920’s and Frank Lloyd Wright’s 1956 ‘Mile High Illinois’. This ambition to build higher and higher continues to challenge the Architects, Engineers and Builders of tall buildings and is expected to continue into the future. The tall building format is clearly here to stay.

“Building Skyscrapers is the nearest peace-time equivalent to war. The analogy to war is the strife against the elements.....Foundations buried deep in the earth alongside existing towering skyscrapers. Water, quicksand and clay block our path to the bedrock. Traffic rumbles in the crowded highways above us and the subways, gas, water-mains, electricity and delicate signal communications demand that they not be disturbed lest the nerve system of a great city be deranged. The service of supply of materials in peace-time warfare, the logistics of building; these men are the soldiers of a great creative effort”


Evolution of Tall Buildings and Current Changes

The development of increasingly sophisticated construction materials and technologies has fuelled the evolution of the modern skyscraper throughout the 20th and early 21st century. The resulting structures have reflected this evolution in the advancement in height, but the overall form of virtually every tall building until fifteen years ago adhered to one of only two design philosophies: the simple extrusion footprint or staggered setback, dictated by planning designed to abate the growing darkness on streets below. In pioneering cities around the world, the majority of designs for tall buildings now reject those conventional limitations with structures that tower, taper, tilt and twist, previously thought impossible to build.

These innovative tall buildings bring unprecedented challenges to the developers, designers and not least, the builders. Technological obstacles must be overcome. Cutting edge design must be converted into a built reality. Safety of its builders and occupants must be ensured. The substantial risk of cost and programme overruns must be minimised. All must be overcome to ensure success of the tall building. As the builders of the Empire State
Abstract

Building, Starrett Brothers and Eken noted “between the completion of the plans and the opening of the doors, it is the builder’s show”.

This EngD research and the resulting thesis explores the challenges that face the builder of tall, increasingly irregularly shaped structures and determines a new solution to one of the most critical issues. This is seen as fundamental to the commercial viability and sustainability of the new breed of tall buildings. To date there has been very little research in this building arena, in contrast to the voluminous research on the urban planning, structural, architectural and services design of tall buildings. This EngD partially redresses that imbalance by presenting three research stages driven by three key objectives:

Objective One
‘Undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors’ - From early 2006 up to the freeze induced by the worlds faltering financial markets during the first quarter of 2008, Britain experienced demand for tall buildings of an unprecedented high level - in London alone, ten tall buildings have started, or were due to start on site between first quarter of 2007 to the fourth quarter 2008. This is directly comparable in size to America’s Manhattan Island skyscraper boom of the 1920’s. A number of important results revealed during this first stage of research were: firstly, investigation into the evolution of the UK tall building construction and determination of the reasons behind its growth at previously unprecedented rates; secondly, creation of a definition of the UK tall building and comparison to the international tall building stage; thirdly, analysis of the differing types of demand and definition of these sub sectors of UK tall building market; finally, the calculation of the size and value of this specialist construction market, forecasting its growth potential and model it against the ‘Skyscraper Index’;

Objective Two
‘Capture and analyse International survey information from Tall Building experts to determine key ‘wins’ & ‘losses’ on tall building projects’ - This research stage captured the global state-of-the-art of the tall building industry. This was achieved by: firstly, designing a questionnaire which tackled the most pressing issues of the tall building process; secondly, targeting the questionnaire at the most active tall building professionals around the globe; and thirdly, gaining an 80% response rate, giving a great insight to the differences of opinion from Dubai to London, China to Chicago, Sydney to Vietnam. The research was conducted in five key areas: the current state-of-the-art of the international tall building industry; the build process of a tall building; the tall building principal contractor key features/issues; ‘wins’ and ‘losses’ inherent with past tall building projects; and new techniques from overseas and other industries that could be adapted to the construction industry. The analysed results lead to some surprising conclusions and offered a clearly signposted way ahead for innovative construction of tall buildings, headlining on ‘expertise of project staff’ and ‘the negative effect of wind’ as two of the most common, critical issues;
Abstract

Objective Three
‘Develop an innovative solution to one of the most critical and common key tall building project losses’ – In this final stage, innovative research was undertaken into the most common critical issue raised by the global tall building experts in the second stage of the research: that of wind and its profound negative effect on the construction critical path of the tall building. Theoretical and aerodynamic research was undertaken, culminating in model making and wind tunnel testing of the ‘Lifting Wing’, a unique design allowing building material to be lifted by tower cranes in higher and more unstable wind conditions.

The Thesis concludes by outlining a number of recommendations for adoption by the tall building industry and suggestions for future research.

KEY WORDS
Figure 0-1 Frank Lloyd Wright’s 1956 The Mile High Illinois
USED ACRONYMS AND ABBREVIATIONS

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<th>Acronym</th>
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<tbody>
<tr>
<td>AAE</td>
<td>Aeronautical and Automotive Engineering</td>
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<td>BLL</td>
<td>Bovis Lend Lease</td>
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<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
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<tr>
<td>CAM</td>
<td>Computer Aided Manufacturing</td>
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<td>CICE</td>
<td>Centre for Innovative and Collaborative Engineering</td>
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<tr>
<td>CDrag</td>
<td>Coefficient of Drag</td>
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<td>CLift</td>
<td>Coefficient of Lift</td>
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<tr>
<td>CM</td>
<td>Construction Management</td>
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<td>CNC</td>
<td>Computer Numerical Control</td>
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<td>CSideforce</td>
<td>Coefficient of Side Force</td>
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<td>EngD</td>
<td>Engineering Doctorate</td>
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<td>GFC</td>
<td>Global Financial Crisis</td>
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<tr>
<td>GMP</td>
<td>Guaranteed Maximum Price</td>
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<tr>
<td>HS&amp;E</td>
<td>Health, Safety &amp; Environment</td>
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<tr>
<td>ICE</td>
<td>Institute of Civil Engineers</td>
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<td>IS</td>
<td>Ian Skelton</td>
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<td>LL</td>
<td>Lend Lease</td>
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<td>LU</td>
<td>Loughborough University</td>
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<td>Multi-Disciplinary Digital Publishing Institute</td>
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<td>Net Trade Cost</td>
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<td>Principal Contractor</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<td>RE</td>
<td>Research Engineer</td>
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<td>Re</td>
<td>Reynolds Number</td>
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<tr>
<td>USP</td>
<td>Unique Selling Point</td>
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PAPER 1 (SEE APPENDIX A)


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PAPER 3 (SEE APPENDIX C)

1 BACKGROUND TO THE RESEARCH

1.1 THE GENERAL SUBJECT DOMAIN

This chapter provides an introduction to the thesis and EngD research which explores the challenges that face the builder of tall, increasingly irregularly shaped structures and determines an innovative solution to one of the most critical challenges in six key phases of work. It sets out the context of the Industry and the Industrial Sponsor, Lend Lease (formally Bovis Lend Lease, preceded by Bovis).

A total of three papers have been published (the first of which was published as a 5000 word version for the ICE Structures and Building Journal, also as an abridged 3000 word version for the ICE Civil Engineer Journal, as well as a revised version for the US, published by ISEC). Paper 1 and 2 were also presented at an ISEC conference, all in fulfilment of the EngD. These are discussed later in this Chapter and are enclosed in Appendix A, B & C.

The research formed six significant work phases:

The first significant work phase was the completion of the five MSc-level modules stipulated by Loughborough University in fulfilment of the formal learning requirements for the Engineering Doctorate. These were carefully selected to align with the needs of the RE in filling knowledge gaps and giving specialist skills needed to achieve the objectives of the EngD. Three modules were successfully completed at Loughborough University, the first CVP008 ‘Research, Innovation and Communication’ in March 2007, the second CVP034 ‘Management and Professional Development 1’ in August 2007 and the third CV035 ‘Management and Professional Development 2’ in the second quarter of 2008. Simultaneously, an MBA module ‘Entrepreneurial and Business Creativity’ and an MSc module ‘Entrepreneurial Strategy’ were both taken during the third and fourth quarters of 2007 at University of Surrey. The final award of ‘Distinction’ for both modules was made by the University of Surrey in the first quarter 2008. In December 2008, following the completion of these formal learning modules, Loughborough University awarded a Post Graduate Certificate with Distinction in Engineering Innovation and Management;

The second significant work phase was undertaking the Literature Review, which captured an over-view of the high rise building market in the UK, calculated its size, and captured its key issues, perceived problems and market growth prospects. A report was generated from the Literature Review and issued to the sponsor company BLL UK Executive Management Team in May 2007. This economic-biased report was stipulated by the BLL EMT as the first output required from the EngD, and its resultant information was planned to inform the business of the scale and growth prospects for the UK tall building market. It was subsequently used to determine the forthcoming BLL UK Three Year Business Plan. The findings of this report were also utilised by the BLL office in Milan and Lend Lease Ventures in Sydney during 2008 to inform business decisions regarding entering the tall building market. The literature review also investigated the current state of innovation in the construction
industry and established the ‘current cutting edge’ for tall building construction and contextualised this against the historic influence of new methods of construction on architectural design.

The third significant work phase was the research undertaken for the writing of ‘Britain’s Tall Building Boom – Now Bust?’ a five thousand word technical paper published by the Institute of Civil Engineers for their Structures and Building Journal (ISI Impact Factor of 2) in June 2009. The ICE also published a three thousand word abridged version of this paper for their July 2009 publication of Civil Engineer (ISI Impact Factor of 1.5);

The fourth significant work phase was the research undertaken for the paper ‘The State of the Art of Building Tall’. This five thousand word paper was published and presented at the 5th International Structural Engineering & Construction (ISEC) Conference at the University of Nevada, Las Vegas in September 2009, along with a four thousand five hundred word version of ‘Britain’s Tall Building Boom – Now Bust?’ paper, revised for the American audience. The research for this paper commenced with targeted structured interviews, held with four major tall building related companies. These interviews gave shape, direction and focus to the designing of the ‘State of the Art of Building Tall’ questionnaire. The questionnaire was tailored to capture the most pressing issues of the tall building process, then issued through a variety of methods, targeting the most active specialist tall building professionals around the globe. The dominant method of targeting the specialist professionals was to hand-issue to a selection of attendees at the Council of Tall Buildings and Urban Habitat (CTBUH) 8th World Congress, held in March 2008 in Dubai, along with hand-issue at the New Civil Engineer’s ‘Engineering Tall Buildings September 2008 Conference’, held in London. An 80% response rate was obtained from these conferences. The results and feedback was collated and analysed to form the basis of this third paper;

The fifth significant work phase was a distinct analysis of the most common and highest ranked tall building ‘losses’ determined from the results and feedback given during ‘The State-of-the-Art of Building Tall’ research. This led to the focus of the final phase of research on the most critical of these ‘losses’ – the critical path effect of wind on construction programme.

The sixth and final significant work phase developed an innovative concept aimed at positively affecting the critical path delay of wind on the construction programme for tall buildings, called the ‘Lifting Wing’. A scale model was been constructed and successfully tested at Loughborough University’s Aeronautical and Automotive Engineering (AAE) wind tunnel during the first half of 2013. This series of wind tunnel tests generated results allowing detailed analysis to be undertaken and conclusion to be drawn, forming the final paper ‘Lifting Wing – Aerodynamic Testing’. This was accepted for publication by the Editorial Panel of Buildings & Engineering Journal and published in May 2014.

As ever, the RE’s motivation, enthusiasm and interest in the topic remain ‘high’!
1.2 THE INDUSTRIAL SPONSOR

Tall Buildings – Bovis Lend Lease Desires & Aims for the EngD

‘With our ever increasing involvement in major high rise projects across the global business, and the ever more challenging designs of these buildings in terms of height, form and complexity, the need for collaboration and knowledge sharing in this specialist field has never been greater’

(John Spanswick, former Bovis Lend Lease Chairman and Global Sponsor of High Rise Community of Practice. September 2006.)

Lend Lease (previously registered and widely-known as Bovis until 2001, then as Bovis Lend Lease until 2012) is an internationally recognised leader in the construction of innovative and challenging projects. This has included tall buildings around the globe. The successful delivery of these projects demands the spanning of divisional, functional and geographical boundaries in order to distil and corral internal high rise experience, bringing innovation, ideas and insights into the way we manage the planning and construction of tall buildings.

This EngD research was initiated in late 2006 and was aimed at exploring the challenges that face the builder of tall, increasingly irregularly shaped structures to determine a new or improved technique, system or method to address one of the critical challenges. The intention was that this would assist Lend Lease regain their position as innovative leaders in the UK construction market by developing a unique selling point (USP) to be utilised when bidding tall building projects and allow the RE to establish a centre of excellence for high rise construction techniques, improving the way Lend Lease compete in the UK high-rise business environment.

At inception, the aim of this EngD was closely aligned with Bovis’s organisational strategy and planned as a USP and key differentiator in winning tall building work. Its outputs were planned to be a valuable resource in developing best practice solutions to meeting future tall building challenges in the UK. This was unfortunately superseded by the global recession from 2007 until early 2013, when demand for tall buildings reduced or disappeared in many countries. The only tall buildings to be constructed during this period were those that had already started or had been committed to financially. Fortunately, this started to change during mid-2013 as tall building projects began once more to make financial sense. Lend Lease was again keen to pursue tall building projects and so the original EngD aim re-aligned with post global financial crisis (GFC) corporate strategy.

1.3 THE CONTEXT OF THE RESEARCH

Bovis Lend Lease Innovation and Performance Department ran an internal national competition in 2006 to find the most suitable candidate to undertake an Engineering Doctorate (EngD) on any proposed topic that was deemed most valuable to Bovis Lend Lease. In August 2006 the RE won this competition with a proposal to undertake the Doctorate on the topic of innovation in the construction of tall buildings. On award, the RE transferred from UK Operations Division to the Innovation and Performance Division. The EngD commenced
and progressed ahead of programme until the RE’s transfer from BLL’s Innovation and Performance Division into the Construction Services Division of UK South in January 2008, when EngD progress faltered due to bidding work commitments. This move was instigated to enable the RE to assist in winning new work for the company and it had several benefits to the work of the EngD, including gaining more tall building knowledge through heavy involvement with two significant tall building bids (Project Centurion, a 46 storey steel framed commercial building in the City of London for JP Morgan with a construction cost of circa £400million and Newington Butts, a 44 storey concrete framed residential tower in Southwark designed by Richard Rodgers for a private Client, construction cost circa £80 million) plus several substantial, high density residential development bids (Project Blue at Chelsea Barracks, construction cost circa £1.6 billion and Penthouses A, B & C at One Hyde Park, Knightsbridge, total construction cost circa £90 million during 2008 and early 2009. This bidding work substantially increased the RE’s knowledge of the each type of construction project, and gave valuable experience of undertaking ‘hook time analysis’ of a steel framed tall building and a concrete framed tall building. This analysis utilised the Bill of Quantities, structural, architectural and services drawings of the two tall buildings to determine all construction materials to be lifted by tower crane or hoist (for smaller materials) and the time taken to lift, land and return to the material pick up point, which ultimately helps build the Construction Programme for a tall building. This analysis also allowed the RE to determine a list of the most commonly lifted materials and their physical dimensions, utilised later in the research for developing the innovative solution named the Lifting Wing. Valuable experience was also gained in cutting edge competitive bidding in a rapidly shrinking market. The demands of this bid work resulted in a delay of six months to the EngD programme. In September 2009, the RE led a bid for a £35million Penthouse C Project for the Prime Minister and Foreign Minister of Qatar at One Hyde Park, Knightsbridge. This prestigious project was subsequently awarded and commenced on site in November 2009, with the RE as Project Director. The project had a planned completion of 23rd July 2012, however several substantial design changes resulted in the completion being extended to 16th November 2012. During this period, research on the EngD slowed and was eventually formally placed on hold via a Leave of Absence granted by the University. The Penthouse Project was successfully completed on programme, allowing the RE to re-register at LU and recommence research in January 2013, with a planned completion date of the EngD of May 2014.

1.4 THESIS STRUCTURE

This Thesis is structured into five remaining Chapters:

Chapter Two, ‘Overarching Aims and Objectives’ presents the CICE and Sponsoring Company demands for the EngD and how these were incorporated into the main aim, the detailed objectives and how this correlates to the published papers. It also clarifies the justification for the research.

Chapter Three, ‘Adopted Methodology’ presents the qualitative and quantitative research methodology selected. It includes the Literature Review, in-depth focused research on critical issues, focus group work, survey and scientific experimentation methods, each used at a different stage of research in fulfilment of the overall EngD requirements.
Chapter Four ‘Research Undertaken’ presents in chronological order the research completed by the RE, commencing with the taught element, the Literature Review, the research into international tall building project critical issues, the focusing on one common and critical issue (that of the effect of wind on the build programme of the tall building), the development of the innovative concept to solve this problem and the experimental analysis undertaken to prove its effectiveness.

Chapter Five, ‘Findings and Implications’ presents the main findings and conclusions drawn from the research. It discusses the impact on the Sponsor Company and for the wider industry. A critical evaluation of the study is discussed and areas for further study are proposed.

1.5 SUMMARY

This Chapter introduced the Industrial Sponsor and its desires for the EngD in the context of the Tall Building Industry. It outlined the resulting EngD research and presented the thesis subject, which is the exploration of the challenges that face the builder of tall, increasingly irregularly shaped structures and determination of an innovative solution to one of the most critical and common challenges. The research work phases and resulting published papers were presented and the structure of the thesis itself was clarified.
2 OVERARCHING AIM AND OBJECTIVES

Loughborough University CICE defines a key aspect of the Engineering Doctorate as the solution of one or more significant and challenging problem with the industry (CICE 2010). The RE and Sponsor Company set the primary aim as the exploration of the challenges that face the builder of tall, increasingly irregularly shaped structures to determine the key ‘wins’ and ‘losses’ and ultimately determine a new or improved technique, system or method to address one of these critical challenges. As research progressed on the EngD, the ranking of key tall building project losses was undertaken, the most critical of these being determined as the effect of wind on the critical path of a tall building, ultimately leading to the invention of a potential solution. In order to achieve the primary aim, a total of three key objectives and five sub-objectives were set to break the research down into meaningful work stages. These are detailed in Section 2.1. The aim and the objectives are detailed in Figure 2-1 below, including reference to the resulting published papers.

![Diagram of Aim, Objectives, and Resultant Published Papers](image-url)

Figure 2-1. The Aim, Objectives and Resultant Published Papers of the EngD
2.1 DETAILED OBJECTIVES

To achieve the primary aim of the EngD, the 3 main objectives and 5 sub-objectives were set to corral and direct the research though the EngD period. These were:

1. Undertake a literature review of tall building construction industry and profile the UK market. Identify key issues, components and problems inherent in the discipline of building tall buildings.
   1.1 Determine the construction value and forecast the potential growth of the UK tall building market. Determine the demand sub-sectors for tall buildings and the drivers for each sub-sector. Determine the threats and opportunities for the market.

2. Capture and analyse International survey information from Tall Building experts to determine key ‘wins’ & ‘losses’ on tall building projects.
   2.1 Design and develop a questionnaire tool to capture key tall building information from expert international tall building project personnel. Apply the tool to capture international high rise project experience from specifically identified leading international tall building specialist, including a cross section of developers, architects, engineers and builders.
   2.2 Distil the international survey information to highlight key ‘wins’ & ‘losses’ on tall building projects.
   2.3 Investigate outstanding project wins. Assess the contributing factors and the environment. Consider adaptations required to allow these international wins to ‘fit’ into UK market.
   2.4 Isolate recurring construction ‘loss’ underlying root causes. Analyse emerging patterns to highlight recurring weaknesses in the approach to high rise construction.

3. Develop an innovative construction technique to overcome one of the root causes of the construction ‘losses’ and that responds to the latest design demands.

2.2 JUSTIFICATION OF THE RESEARCH

The construction industry has long had a reputation of lacking innovation, being slow to develop and risk averse. This was famously reinforced by the findings of The Latham Report ‘Constructing the Team’ (Latham, 1994) and followed up by The Construction Task Force headed by Sir J Egan ‘Rethinking Construction’ HMSO (Egan, 1998). Perhaps unsurprisingly, the industry has been traditionally slow to react to these findings, however in more recent years the most proactive main contractors and sub-contractors have become keener to improve their image by investing in innovation and development as they see this as a unique selling point (USP) in the very competitive post-recession market place. BLL recognised this and saw the EngD output as a potential USP or key differentiator for one of their targeted growing specialist markets, the tall building.

This EngD research was initiated in late 2006 and was aimed at exploring the UK tall building market and the challenges that face the builder of tall, increasingly irregularly shaped structures to ultimately determine
a new or improved technique, system or method to address one of the critical challenges. The intention was that research would assist BLL regain their position as innovative leaders in the UK construction market by developing a USP to be utilised when bidding high-profile tall building projects and allow the writer to establish a centre of excellence for high rise construction techniques in the UK.

BLL had previously won and built numerous notable tall buildings across the world including Petronas Towers in Kuala Lumpur, Trump Towers in New York, Aurora Place in Sydney and Bishopsgate Tower and early works on 122 Leadenhall in London. However, BLL were replaced on Leadenhall following the project being placed on hold due to the financial recession and subsequently did not win a tall building tender for several years. Additionally, many of the key personnel directly involved with these tall building projects had left the company. Once BLL commissioned the RE to commence the EngD, an internal report was requested to be presented to the UK Board determining the tall building market size, value and growth potential. This report showed that from early 2005 Britain was experiencing a demand for tall buildings of an unprecedented high level. In London, five tall buildings were due to start on site between first quarter 2005 to the first quarter of 2006 and more tall buildings were being worked on by architectural practices in London than ever before. BLL decided they wanted a share of this market and recognised that they needed to regain the cutting-edge tall building knowledge and a USP to win such projects. The EngD was a direct result of this desire.

2.3 NOVELTY OF THE RESEARCH

This EngD research explores the challenges that face the builder of tall, increasingly irregularly shaped structures and aims to determine a new solution to a key project loss, which is deemed fundamental to the commercial viability and sustainability of tall buildings. The information gathered and analysed for this EngD has in many instances been determined first-hand from first principles, as sector specific information for the tall building construction market does not readily exist. Data was compiled and extrapolated from standard construction market sector information, then filtered against a number of criteria to provide meaningful tall building results. The Literature Review showed that to date there had been very little research in this building arena, in contrast to the voluminous research on the design of tall buildings. This EngD aims to redress that imbalance.

2.4 SUMMARY

This Chapter clarified the primary aim of the EngD, distilled from the key requirements of the CICE and BLL. From this, three key objectives and numerous sub-objectives were established to fulfil the requirements of the EngD. The research justification was also presented.
3 ADOPTED METHODOLOGY

This chapter provides an overview of the considerations recognised in the selection of the methodology, the individual methodologies adopted in each stage of the EngD research and the ability of each to achieve the research objectives presented in Chapter 2.

3.1 METHODOLOGY OVERVIEW

The EngD research methodology was broken down into two main stages involving several distinct methodologies. Multiple research techniques or procedures were actively used to gather and analyse the specialist data needed for the Thesis. This ‘mixed research method’ has been recognised as having a beneficial contribution to the findings due to reduced or eliminated disadvantages of each individual approach, whilst maximising advantages (Fellows & Liu, 2003). The mixed research method is described below:

Stage 1: International best practice tall building research (Background Theory) leading to the key ‘wins’ & ‘losses’ on tall building projects (Focal Theory);
Stage 2: Research focusing on a single key ‘loss’ and developing a theoretical solution (Data Theory) then proving the theoretical solution with innovative research (New Contribution).

![Figure 3-1. Research Stages, Objectives and Methodologies.](image)

Stage one research was initiated with Background Theory, undertaken to provide an understanding of the current high rise construction market. This commenced by undertaking a Literature Review of the tall building industry, academically recognised as the most effective method to determine the status of the chosen research field by providing the ‘foundation’ of knowledge. The Literature Review was undertaken by reviewing previous published research work highlighting common themes, arguments, gaps in current understanding and ultimately isolating areas warranting further research. The findings from this Literature Review were then utilised to generate the Market Report, primarily to satisfy the initial requirement of the Sponsoring Company. The report was designed to help convey an understanding the market sector, allowing the company to decide if it was deemed a commercially desirable sector and help determine what measures would need to be taken for the sponsor company to re-enter this market. The stage one research then progressed on to Focal Theory. This methodology allowed the cataloguing of best practice techniques or ‘wins’ both within and external to BLL,
allowing comparisons across the globe to be drawn. This would highlight common critical ‘loss’ areas that lack a cutting-edge or state-of-the-art approach.

Stage one research acted as the springboard for stage two, which commenced with Data Theory assisting in focusing the research toward one common and critical tall building ‘loss’. This in turn led to the creation of an innovative solution, or concept. The final methodological approach was New Contribution, the proving of the concept through a blend of established academic theory and innovative testing and experimentation.

### 3.2 METHODOLOGICAL CONSIDERATIONS

The CICE and the sponsoring company (BLL) requirements were at the forefront of determining the methodology of the research. The CICE state ‘a fundamental element of a successful EngD is the contribution to a solution of a significant and challenging engineering problem’. Similarly BLL required the EngD to ‘span divisional, functional and geographical boundaries in order to distil and corral internal high rise experience, bringing innovation, ideas and insights into the way we manage the planning and construction of tall buildings’ (Spanswick, J. BLL Chairman). These two key requirements led to the methodology strategy utilised in the delivery of the EngD research. Flexibility and dynamism also had to be built into the research methodology to react to dramatic cyclical changes to the marketplace resulting in changing desires from the Sponsor Company, particularly prevalent through the GFC of 2008 – 2013.

### 3.3 METHODS USED

A mix of quantitative and qualitative research methods were planned to be used during the research process to maximise benefits and minimise the disadvantages of each individual approach. This ‘mixed methods’ approach reduces or eliminates recognised disadvantages with each distinct approach whilst maintaining their advantages (Fellows & Liu, 2003). Within the four research theories described in the following section, five distinct methodologies were utilised at various stages of the research. These included: Action Research (collaborative problem solving); Focus Group (group discussion based interviews determining the jointly understood conclusion); Survey (systematic data collection from a defined population); Statistical Analysis (interpretation of this survey data) and Experimental Research (experiments undertaken in controlled environment with controllable variables); all recognised research styles (Fellows & Lui, 2003).
3.3.1 STAGE 1

BACKGROUND THEORY

Literature Review and Market Report

The methodology adopted for the Background Theory was an extensive literature review of tall building academic research and of the UK tall building market. This provided the foundation of knowledge for the EngD research to build upon and allowed the refinement of the objectives and methodology adopted. It produced new data allowing the Net Trade Cost of the tall building market to be calculated and captured the ‘first draft’ of the market’s key issues, perceived problems and market growth prospects. It also showed gaps in previous research and highlighted areas for further research. This report was issued to the Bovis Lend Lease UK Executive Management Team in May 2007. The findings of this report have subsequently been utilised by the BLL office in Milan and Lend Lease Ventures in Sydney during 2008 to position the company for future tall building work.

This work satisfied Objective 1, to ‘undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors’.

FOCAL THEORY

Key Tall Building ‘Wins’ and ‘Losses’

This initial literature review was then focused on several key areas of research and supplemented in depth during the Focal Theory stage of the research. This was undertaken in two steps:

Firstly, the data gained during the literature review was investigated in more detail for the seventeen key findings determined as of critical importance to the UK Tall Building industry. This formed the basis for the first paper ‘Britain’s Tall Building Boom – Now Bust?’ published by the Institute of Civil Engineers for their Structures and Building Journal in June 2009 (Appendix A). An abstract for the paper follows:

‘From early 2006 up to the freeze induced by the worlds faltering financial markets during the first quarter of 2008, Britain experienced demand for tall buildings of an unprecedented high level – in London alone, ten tall buildings have started, or are due to start on site between first quarter 2007 to fourth quarter 2008. This is directly comparable in size to America’s Manhattan Island skyscraper boom of the 1920’s. The objectives of this paper are: Firstly, to investigate the evolution of the UK tall building construction and determine the reasons behind its growth at previously unprecedented rates; Secondly, to create a definition of the UK tall building and compare it to the international tall building stage; Thirdly, to analyse the differing types of demand and define these sub sectors of UK tall building market; Finally, to calculate the size and value of this specialist construction market, forecast its growth potential and model it against the Skyscraper Index.’

The seventeen findings of the research for this paper were distilled down to nine key results for the first publication and are discussed in Chapter 5 ‘Findings and Implications’, Section 5.
Secondly, Focus Group and Survey methods were utilised to gain the data for the second paper ‘The State of the Art of Building Tall’, published and presented at the 5th International Structural Engineering & Construction (ISEC) Conference at the University of Nevada, Las Vegas in September 2009.

The research for this second paper involved understanding the specific issues associated with building a tall building and the ‘wins’ and ‘losses’ experienced during the process. This commenced with Focus Group semi-structured interviews, held with four tall building project construction Company Directors, one of which was internal to BLL. Two sets of these interviews gave shape, direction and clarity to the designing of the ‘State of the Art of Building Tall’ questionnaire. This led to the next stage of research utilising Survey methodology. A questionnaire was tailored from feedback gained during the Focus Group to clearly capture the most pressing issues of the tall building process and allow them to be rated and ranked. It was issued to a defined population of the most active tall building professionals around the globe, as well as being hand-issued to targeted specialist professionals attending the Council of Tall Buildings and Urban Habitat (CTBUH) 8th World Congress, held in March 2008 in Dubai and the New Civil Engineer’s ‘Engineering Tall Buildings September 2008 Conference’, held in London. The results gained from the questionnaire responses were analysed and formed the basis for the second published paper ‘The State of the Art of Building Tall’ (Appendix B). An abstract follows:

‘Following on from the first published paper titled ‘Tall Building Boom - Now Bust?’ which concluded that Britain's demand for tall buildings of an unprecedented high level, directly comparable in size to Americas Manhattan Island skyscraper boom of the 1920's, but was ultimately heading for a recession, this second paper determines the global state of the art of building tall. This has been achieved by firstly designing a questionnaire which tackles the most pressing issues of the tall building process, secondly, targeting the questionnaire at the most active tall building professionals around the globe and thirdly, gaining an 80 % response rate, giving a great insight to the differences of opinion from Dubai to London, China to Chicago, Sydney to Vietnam. In summary, this paper investigates five key areas: the current state-of-the-art of the international tall building industry; the build process of a tall building; the tall building principal contractor key features/issues; lastly, wins and losses inherent with past tall building projects; new techniques from overseas and other industries.

The analysed results lead to some surprising conclusions and offer a clearly signposted way ahead for innovative construction of tall buildings.’

The work undertaken to this point satisfied Objective 2, to ‘capture and analyse international survey information from tall building experts to determine key ‘wins’ & ‘losses’ on tall building projects’.
3.3.2 STAGE 2

DATA THEORY
Focus on a solution to one Common and Critical ‘Loss’ with theoretical research

This involved isolating the construction ‘losses’ reported in the above work, analysing the underlying / root causes and determining the most important loss upon which to concentrate efforts to mitigate or solve. A clearly recurring theme of the analysed questionnaire responses returned from the Dubai and London conferences was that wind had a critical impact on construction risk and the ability to deliver surety in programme and therefore cost of a tall building. This lead to a focus on investigating ways to mitigate the effect of wind on the most critical single element of building a tall building - the tower crane. Two ideas were conceived, both aimed at increasing the safety and speed of construction of tall buildings. They were christened the ‘Mag Spanner’ and the ‘Lifting Wing’. They were both aimed at satisfying the diametrically opposed needs of time, cost, quality and safety on tall building projects. The mag spanner was quickly developed and has been introduced on many BLL steel frame projects with a significant reduction in the number of dropped bolts, washers and spanners. The Lifting Wing was deemed the more important of the two innovations having the most profound potential benefit and therefore became the focus for the final stage of research.

NEW CONTRIBUTION
Test and Prove the Innovation

This stage of the research was the development of one innovative construction technique to overcome a root cause of a key construction ‘loss’. Of the two innovative ideas conceived during the research, the concept with the biggest potential impact on speed of construction of tall buildings was determined to be the Lifting Wing. This was demonstrated to have the potential to reduce the tall building industry accepted norm of 40% down-time for a tower crane, thereby saving time on the critical path of the tall building construction programme and hence, substantial costs. Experimental methodology was employed to test the concept. This initially involved theoretical aerodynamic development, followed by scale model building and finally obtaining quantitative data from wind tunnel testing and qualitative date from flow visualisation and dynamic testing.

The results gained from the experimental analysis formed the basis for the final published paper ‘The Lifting Wing In Constructing Tall Buildings – Aerodynamic Testing’, published in May 2014 in MDPI AG Buildings & Engineering Journal (Appendix C). An abstract follows:

This paper builds on previous research by the authors which determined the global state-of-the-art of constructing tall buildings by surveying the most active specialist tall building professionals around the globe. That research identified the effect of wind on tower cranes as a highly ranked, common critical issue in tall building construction. The research reported here presents a design
for a ‘Lifting Wing’, a uniquely designed shroud which potentially allows the lifting of building materials by a tower crane in higher and more unstable wind conditions, thereby reducing delay on the programmed critical path of a tall building. Wind tunnel tests were undertaken to compare the aerodynamic performance of a scale model of a typical ‘brick shaped’ construction load (replicating a load profile most commonly lifted via a tower crane) against the aerodynamic performance of the scale model of the Lifting Wing in a range of wind conditions. The data indicates that the Lifting Wing improves the aerodynamic performance by a factor of 50%.

This work satisfied Objective 3, to ‘develop an innovative solution to one of the most critical and common key Tall Building Project ‘loss’.

### 3.4 SUMMARY

This chapter detailed the methodology adopted in each stage of the research, structured to achieve each of the research objectives discussed in Chapter 2 whilst being flexible and dynamic to accommodate changing demands from the sponsoring company. A mix of quantitative and qualitative research methods were used as the research progressed to maximise benefits of each. Literature Review, In-depth Focused Research on critical issues, Focus Group, Survey and Experimentation methods were all utilised in fulfilment of the EngD requirements.
4 THE RESEARCH UNDERTAKEN

4.1 INTRODUCTION

This chapter describes in chronological order, the original research work completed to fulfil the aims and objectives of the EngD, as described in Chapter 2 and in accordance with the research methodology clarified in Chapter 3. Each activity is then described in detail and the relevance to the EngD research is explained. Reference to the published papers (Appendix A-C) is made where relevant.

4.2 RESEARCH ORDER

The order in which the research was carried out was dictated by the set objectives, with the exception of the Taught Element which was a CICE mandatory requirement to be completed in the second year of the EngD.

Firstly, the Literature Review of tall building construction was undertaken and the UK tall building market was profiled. Investigation into the future of tall buildings generated a working list of areas for latter stage EngD research.

Secondly, a questionnaire tool was designed and developed to capture key information on the international tall building process. This was used to capture key information from specifically identified leading international tall building professionals over a market cross section of developers, architects, engineers and builders. This information was analysed to highlight key ‘wins’ & ‘losses’ on international tall building projects. The outstanding project wins and recurring construction ‘losses’ were analysed to highlight recurring weaknesses in the approach to high rise construction and possible areas for improvement.

Thirdly, one of the most common and critical construction ‘losses’ was selected as the focus for development of the innovative construction solution. This idea was developed by critiquing it against established theory. The resulting refined design was then modelled and wind tunnel tested to validate the innovation.

The detail of the research undertaken is presented below.

4.3 TAUGHT ELEMENT

The successful completion of a maximum of six MSc-level modules totalling 60 Credits was stipulated by Loughborough University in fulfilment of the formal learning requirements for the Engineering Doctorate. These were to be completed within the first two years of the EngD and were carefully selected by the RE, where not mandatory courses, to align with the needs of the RE, filling knowledge gaps and giving specialist skills needed to achieve the objectives of the EngD. The sixty Credits were achieve with five selected modules.

Three modules were successfully completed at Loughborough University, the first CVP008 ‘Research, Innovation and Communication’ in March 2007, the second CVP034 ‘Management and Professional
Development 1’ in August 2007 and the third CV035 ‘Management and Professional Development 2’ in the second quarter of 2008. Each was awarded ‘with Distinction’ by CICE, LU.

An MBA module ‘Entrepreneurial and Business Creativity’ and an MSc module ‘Entrepreneurial Strategy’ were taken during the third and fourth quarters of 2007 at the University of Surrey. Each was awarded ‘with Distinction’ by SU.

Additional skills training activities were undertaken during 2008. These topics selected for training fulfilled the writer’s skill gap requirements and allowed fulfilment of the Management and Professional Development Module CVP0035, the final stipulated LU taught element of the EngD:

1. Corporate Strategy

This involved a literary review of corporate management theory followed by a comparison to BLL UK’s developing strategy. These findings were utilised to assist in the setting up of BLL Construction Services strategy to deliver the LL Corporate Vision. It developed a clear understanding of corporate strategy which assisted in translating the tall building specialist service vision developed through the EngD, into a feasible proposition fitting within the latest BLL corporate strategy.

2. Business Plans and Objectives

This required improving skills in developing business objectives and business plan writing and has allowed the progression of the tall building concept products currently being worked up through the EngD toward a marketable product. This followed on from the corporate strategy skill in providing the next step in the development of the tall building business strategy to a feasible business proposition. A literature review of business plan writing and development theory was applied to the context of the UK tall building market and allowed the feasibility of the tall building concept products to be investigated. A business plan was written for future consideration by BLL.

3. Business Analysis (Strengths, Weaknesses, Opportunities and Threats, SWOT)

This involved a literature review of business analysis theory and application to the UK tall building market for the innovative products under development in the EngD. Skills gained in undertaking this research were used to clarifying how the proposed tall building innovative product would fit in the market, which competitors exist, what they offer and the size of the market. This helped in proving the business case for the product. The result were a picture of the market fit, the product strengths, weaknesses, opportunities and threats, lending weight to proving the business case.
4. Proposals and Presentations

This involved reviewing the latest proposal and presentation techniques used in the construction industry, determine what the best of LL’s competitors were doing in this field and determined the best approach for the proposal document and presentations for a live project bid, running from May 2008 to November 2008 (Project Blue, a £1.6 billion super-prime residential development for developers Candy & Candy at Chelsea Barracks in London). The presentation and proposal techniques learned were also utilised to internally promote the EngD primary output, the Lifting Wing concept. The development of these skills was immediately required to help sustain the funding of the EngD which was under threat through the initial UK economic recessionary period from 2008 – 2009. Internal promotion to the LL Executive Management Team of the potential benefits of the EngD outputs assisted in retaining funding to complete the EngD. These presentation skills were also used in fulfilling the RE’s Construction Services role, bidding for tall buildings and ensuring submitted presentations were of an industry-leading standard.

5. Implementation of Best Practice

This involved research into the specialised sub-sector of the tall building industry, the supplier of tower cranes. The research determined the current UK best practices to maximise tower crane efficiency whilst maintaining or improving safety on large projects. The factors influencing crane efficiency were determined and methods to tackle these were investigated. The information gathered during this research was been beneficial in proving the case for the Lifting Wing concept.

Additionally, skills were developed in the specialised area of scale model making and aerodynamics, involving the theoretical analysis, design, building and wind testing of scale models at Loughborough University’s Aeronautical and Automotive Engineering Department. This culminated in the wind tunnel testing of the scale models of the Lifting Wing and Brick.

The final award of ‘Distinction’ for the MBA module ‘Entrepreneurial and Business Creativity’ and an MSc module ‘Entrepreneurial Strategy’ was made by the University of Surrey in the first quarter 2008. This award formally completed the requirements of the taught element of the Engineering Doctorate and in December 2008 Loughborough University awarded a Post Graduate Certificate with Distinction in Engineering Innovation and Management.

### 4.4 LITERATURE REVIEW

This section details the research undertaken for the Literature Review. This was undertaken to fulfil Stage 1 Background Theory and Objective 1 of the EngD research, ‘Undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors’. The Literature Review commenced at the
outset of the EngD, running in parallel with the Taught Element, but continued until May 2007. Once complete, it provided a solid foundation of knowledge to commence Stage 2 of the research. A summary of the findings of the report resulting from the Literature Review is included in this section of Chapter 4. The full report was issued to the BLL Board in May 2007 and utilised to inform business strategy for the following 3 year business plan. The full report is included in Appendix D. All results and conclusions were correct at that time.


Figure 4-1. Future 150m+ Skyline of London?

Report Introduction

This report was the result of first-hand, first principles research into the tall building market sector of the UK construction industry. The objectives of this report were:

- To analyse the size of this specialist market and determine the potential value of this market to Bovis Lend Lease;
- To analyse the reasons why the local market is currently growing at an unprecedented rate, understand the types of demand and forecast its growth potential;
- To explain the UK tall building in a Global tall building setting;
- To determine the nature and structure of the tall building industry, the business models, risk profile and its supply chain characteristics;
- To consider how these factors influence the delivery of tall buildings in London to achieve the Mayor of London’s target, meet the unsatisfied demand of client's tall building requirements and aspirations;
To determine Bovis Lend Lease’s current market position, review what the competitors are doing differently, outline market opportunities and provide new data on which a Bovis Lend Lease tall building strategy can be based;

To investigate typical cost and revenue generators for tall buildings;

To provide innovative data worthy of future publication, in partial fulfillment of the Engineering Doctorate requirements.

The report was in three parts:

- **Part I** - Evolution of the UK Tall Building and the EngD. Key information from this report is utilised in Paper 1 in Appendix A.

- **Part II** - The Market Analysis. This sets out in detail the state-of-the-art of the UK Tall Building market, calculates its current value at nearly £10 billion (Net Trade Cost) and forecasts its growth prospects. Key information from this report is utilised in Paper 1 in Appendix A. The full report is included in Appendix D.

- **Part III** - The Future of Tall Buildings – This set out potential areas for further study during the remaining research period of the EngD and sought BLL EMT direction on the what was deemed most valuable or business relevant topics, assisting in the final selection of the area for further study.

Executive Summary

This Market Analysis section of this report created a valuable and unique snapshot of the UK tall building market. It included the current state and types of demand and supply, the market’s current value and its forecast growth. The information contained in the analysis has been determined first-hand from first principles, as sector specific information for the tall building construction market does not readily exist – it has to be compiled by hand and extrapolated from current generic information for the standard market sectors, then filtered against a
number of criteria to provide meaningful tall building results. The full picture of the tall building market presented in this analysis has been built up from a blend of new data generated during this research, live information from industry recognised expert sources, plus theoretical and professional knowledge. This market analysis concentrates on London as this forms almost 70% of the current UK tall building market, but also considers all areas of the UK. This analysis made seventeen key findings:

- The tall building form is not a passing design fad in the UK, it is here to stay and is currently backed from the upper echelons of Central Government down to popular public opinion;
- The UK tall building is defined in this report as a building of a height of twenty stories and greater, due primarily to the change in building methodology required, but this only equates to mid-rise on the international skyscraper stage;
- Several new tall building clusters are being encouraged in London by Central Government, the Mayor’s London Plan, CABE and by unsatisfied demand from the office, mixed use and residential sectors;
- The biggest threat to the continued growth of the London tall building market was considered to be UNESCO’s pressure to stop tall buildings close to heritage sites of London and Liverpool. This was fostered by Ruth Kelly’s (previous Secretary of the State at the Department of Communities) anti-tall building stance, resulting in a Public Inquiry for 20 Fenchurch St. An anti-tall building precedent was expected to be set, but the Inquiry gave approval, due mainly to the replacement Secretary of the State at the Department of Communities (Hazel Blears) being more supportive of tall buildings.
- There are four types of London tall buildings driven by four distinct areas of demand: the fat office tower (18% of market demand); the skinny/iconic office tower (36%); the mixed use tower (18%) and the residential tower (28%); as evidenced in the Tall Building Market Sector Report, Appendix D;
- The sum of these four markets means that the current high demand for tall buildings is unprecedented – ten London tall buildings are due to start on site in 2007. This is directly comparable in size to the Manhattan skyscraper boom of the 1920’s;
- Capable tall building main contractors are now hardening their commercial stance by becoming more selective, more risk averse and demanding a higher price. Tall building Clients are increasingly having to use two stage or negotiated tenders to secure an experienced tall building main contractor;
- Bovis Lend Lease are consistently in the top three constructors of offices within the tall building market sector, but do not rate in the residential sector of tall buildings;
- Bovis Lend Lease’s biggest tall building competitors are Carillion, Skanska, Mace and Laing O’Rourke (plus several residential tower builders). Each of these competitors has recognised tall buildings as a target sector and have significant capital invested in specialist divisions to bring in tall building work;
- High barriers to entry minimise the likelihood of increasing overseas competition for the construction of UK tall buildings;
- London has thirty nine tall buildings potentially reaching site in the next three to five years, the South East has four and the balance of the UK has fifteen. The total estimated net trade cost of which is £9.957 Billion.
- If BLL win only 5% of tall buildings in London and the South East (which equates to winning just over two of the total forty seven projects proposed in this region) it would bring in £47million (net trade cost) per annum for circa eight years (the average gestation and build period of a UK tall building);
- If BLL win 5% of all UK tall buildings it would bring in £62million (net trade cost) per annum for circa eight years;
- The average view of the independent economic forecasts considered for years 2007 to 20011 is one of sustained growth for both the commercial and residential drivers of the tall building market, with an increasing focus on mixed use (part commercial and part residential space) towers as the most efficient way forward;
- Costing models indicate twenty stories as the optimum height for tall buildings - there is an exponential growth in cost from twenty to forty stories, which then levels out at the fiftieth storey. This is discussed in the Tall Building Market Sector Report, Appendix D;
- There are fifteen key cost generators and four revenue generators identified for a typical tall building, again discussed in the Tall Building Market Sector Report, Appendix D;
- Methods for increasing levels of prefabrication, mitigating the effect of wind on tall building construction have been identified as warranting further study, as does speed of construction versus cost and international best practice build methodology. These are possible areas for further research during the EngD;

The facts behind these seventeen key findings are explained in more detail in the body of the market analysis - Tall Building Market Sector Report in Appendix D.

In conclusion, this report found that the UK tall building construction market offers a considerable opportunity for BLL immediately and over the next ten years. It is clear from the findings that a strategy needs to be formulated to maximise on this market potential, whilst minimising operational risk. The report also clarifies that BLL needs to capitalise on its in-house specialist skills and reputation as a builder of high quality tall buildings, which should grow in stature once Bridgewater Place is handed over and as 201 Bishopsgate, 122 Leadenhall and Newington Butts are successfully started on site. Capable tall building main contractors have all hardened their stance in the UK market and tall building clients are increasingly using having to use two stage or negotiated tenders to secure an experienced tall building contractor. The market was seen to bear a higher contractor reward for the high risk of building tall.
Early ideas to be used in the formulation of a BLL tall building market strategy by the RE included methods to gain an early position on tall building projects. These included: the utilisation and growth of in-house expertise to give tall building advice earlier in the project life cycle (concept design stage); the potential benefit of the procurement of, or partnering with, a tall building specialist service provider (such as tall building cranes, logistics, high speed hoisting, etc.) again, aimed at gaining an early position on the project; plus the development of an innovative concept to assist in the building of tall buildings. This last idea was deemed the most favourable outcome as it would provide a USP for the sponsoring company in a competitive market.

The Future of Tall Buildings – Potential Areas for Further Study

Innovation in Tall Buildings

Tall buildings are recognised as a test-bed for innovations in the building industry. Following successful application on a tall building, innovations then percolate down to the wider industry and other building types. (Reina, 2009). One of the most successful tall building design innovations to date was unitised cladding (finished glazing, frame & gaskets delivered to site as a prefabricated panel to be internally fixed), first developed for use on American tall buildings, it is now widespread. Advantages include a safe, rapid and higher quality installation of a cladding system available to commercial, residential and even industrial buildings worldwide. A more recent example of tall building innovation is the pioneering use of robotic cleaning on the Mori Tower in Shanghai built in 2005. One of the next big-impact design innovations yet to be built, but theoretically designed, could be the use of multiple shuttle cars in a single lift shaft, the next progression on from recent vertical circulation
innovations such as sky lobbies, destination hall-call systems and double-decker lifts. This would have a
dramatic effect on the ability to build higher with fewer cores, substantially increasing net letable area of tall
buildings and therefore their commercial feasibility.

Innovation in the construction of tall buildings centres on the efficient management of a build process and the
achievement of speed safely. ‘The principle function of the builder of tall buildings is not to erect steel, brick or
concrete, but to provide a skilful, centralised management for coordinating the various trades, timing their
installations and synchronising their work according to a predetermined plan, a highly specialised function the
success of which depends on the personal skills and direction of its staff’ (Starrett, W. 1928). Following this
mantra of management of men, materials and money, Bill Starrett’s company, Starrett Brothers & Eken
successfully built the 86 storey Empire State building from foundations to occupancy in less than one year,
achieving one storey a day for a 10 day period. The planned durations for the key trades were: steel frame, 3.5
storeys per week; brick walls, a storey a day; stonework cladding, 2 stories a week. Trade workers peaked at
3500 on site (Willis C 1998). These build rates are the only record that the Empire State Building still holds
today (it was beaten in height in the 1970’s by New York’s World Trade Centre, then Chicago’s Sears Tower )
and is still an unattainable goal for the modern tall building some 70 years later.

Unlike the well-defined problems facing the design team, builders have to deal with external conditions beyond
their direct control such as the availability of raw materials, fluctuations in labour and material prices, and most
importantly, transportation of men and materials to meet programme. As William Starrett wrote in skyscrapers
and the Men who Build Them (1928) ‘Building Skyscrapers is the nearest peace-time equivalent to war. It is
strife against the elements…the service of supply in peace-time warfare. The logistics of building and these men
are the soldiers of a great creative effort’. Logistics is therefore recognised as one of the key challenges to the
success of large building projects and is one of the oldest problems. The oldest known construction law is the
prohibition on daytime passage of carts bearing building material through the streets of Imperial Rome. Logistics
for the tall building was therefore warranted as an area for further study during the EngD.

Innovation in Construction

Historical studies show that new ideas are slow to be accepted in the construction industry. Traditionally a long
path is followed with the commonly recurring stages of; inception of the idea, testing of prototypes, trial use,
failure, gestation on the shelf, reinvention, retrial, success through construction of a seminal building, adoption,
misuse, rejection due to failure, introduction of legislation to control its use, gradual improvement of the material
or technique and finally, general acceptance (Strike 1991).

According to Leading Edge White Paper W/G1 on innovation (Leading Edge, 2006), the British Construction
Industry has appetite for incremental innovation as opposed to radical innovation (deemed to carry the highest
risk and highest potential returns). This taste for low risk product augmentation is due to market pressure for
quick profits, fast growth and share price dependency. This incremental innovation is also due to the marketplace
being mature and crowded. Within the building industry it is believed that differentiation can be achieved by
improving existing products, but competitor imitation can lead to cynical customers refusing to pay more. This
can then lead to discounting to increase sales volumes leading to low prices and little recovery prospects. This
has happened periodically in the construction market where companies have resorted to ‘buying’ competitive tender projects to maintain turnover and profile in the market place. This means the market is ready for substitute products or services that outmode the traditional market. The Lifting Wing innovation fulfils this definition.

The construction industry is traditionally adverse to high risk, break through innovation. The constraints inherent in the construction industry in promoting this type of innovation are (Ettlie, 2006):

- Clients or their procurement managers who are risk averse and stick to who they know;
- No structured innovation process to manage risk, leading to expensive failures;
- Need for complex formal analysis and metrics to prove investment potential of innovation;
- Genuine complexity of market opportunities;
- Companies fear of failure in tight job markets.

Overcoming these obstacles within BLL was determined as fundamental to the success of creating the tall building USP required to raise BLL’s profile in the market.

The type of innovation sought by BLL then needed to be clarified. An established framework for innovation in the construction industry is The Three Zones of Innovation (Leading Edge, 2006):

- Zone 1 Basic Innovation: minor enhancement to an existing product or service giving short term returns and saturated markets;
- Zone 2 Relative Innovation: Adapting an existing product or service for new markets;
- Zone 3 Concept Innovation: Creation of new product or service, break through business models or value propositions. These have greater perceived risk and returns.

The focus of the latter stages of the EngD was agreed with BLL EMT to be on Zone 2 and 3 innovations. A working list of ideas generated whilst undertaking the EngD research was used to understand the scope of potential improvement areas during the Background Theory stage, until focus was turned on only one key idea for further development during the Focus and Data Theory stages of research, thereby fulfilling the second set of objectives detailed in Chapter 2.

Two other key areas researched in depth as part of a Literature Review but that did not ultimately get selected for final stage innovative research were the prefabrication of tall buildings and improving safety in tall buildings through minimising falls from height. The findings are discussed briefly below.

**Can Tall Buildings be prefabricated?**

Tall buildings are laboratories for design and construction. There will be problems associated with innovative solutions - economies of scale cost implications of the small volume of production, learning curve productivity issues etc. According to The Housing Forum (THF 2001), the advantages off-site fabrication for house building include 50% reduction in handover defects, up to 50% saving on construction time and less weather and vandalism risk to building and materials through earlier closure. Off-site fabrication requires substantially more
engineering to work effectively on tall buildings, but modular suppliers are actively researching this area and have successfully built up to 14 stories to date.

(Forbes, 1996) argues the development of high strength concrete, which can be pumped 500m above ground is the biggest factor against prefabrication. Its success has led to a trend across Australia for tall buildings constructed in insitu concrete (transported as a liquid to its final position in a building and poured into steel, plastic or plywood formwork). In the Middle East the Burj Dubai structure was built predominantly from high strength, super plasticised, chilled concrete. However, there are huge potential benefits of prefabrication in building tall due to the largely repetitive nature. This area was selected as a potential area to be investigated in detail during the research as a potential innovation area, but was ultimately not taken forward due to the results of the Focus and Data research stages indicating other areas having greater potential benefit.

Safety in Tall Buildings

Safety in the construction of tall buildings has always been a crucially important part of building, due in part to the high profile level of interest that the construction process generates, plus the public’s daily visibility into the works. Since 9/11, safety has become the focus of more disciplines in the tall building arena, but this effort has focused predominantly on design changes for life safety systems and limited structural changes, rather than the construction process itself.

One of the earliest records of investment in significant safety systems employed in the construction of tall buildings is that of the Empire State Building. Contrary to popular belief, Starrett Brothers & Eken, the builder of the Empire State Building were very concerned with safety and undertook numerous innovative measures to increase mechanisation and ensure accidents were limited, even if it was believed at that time, some were inevitable (Willis 1998). There were six deaths of construction workers on the Empire State and one death of a member of the public, struck by falling timber, but Starrett & Co made substantial inroads towards a safer process through mechanisation of construction.

The methods of erection have become substantially more mechanised since the 1930’s and the increasing use in off-site production for elements of a tall building mean fewer onsite resources are required to construct a building of similar scale today. A 3500 peak labour level for the Empire State Building would be circa 800 using modern methods of construction. This reduced number would greatly assist in reducing the risk of accidents.

However, the main cause of accident on tall buildings is falls – either materials or man. This area was researched in more detail as part of this study and culminated in the innovation named the ‘Mag Spanner’. Early Focus Group interviews undertaken by the RE with the Project Directors of two BLL tall building projects had shown that dropped bolts, nuts, washers and shims were the most frequent ‘near-miss’ safety occurrence on site. This was caused when the structural frame installers working at height, commonly in adverse weather conditions, dropped one of the fixing items (nut, washer, bolt or the spanner). To reduce this risk the RE developed a magnetised socket-spanner which allowed the nut head and washer to be safely held in one socket head, whilst the bolt was safely held within the other, released only when the elements had been securely bolted together. Both spanners were securely attached to the steel fixer’s belt with a karabiner and an elasticated shock chord. In
trials on a BLL steel frame site, the Mag Spanners were well received by the steel frame contractor and their operatives and as a result the number of items dropped from height over the period tested reduced significantly. It has since been adopted on several UK BLL sites utilising steel structural frames.

Literature Review Summary

The extensive literature review achieved the following objectives that the sponsor company had defined as desirable EngD outputs:

- determine the size of this specialist market and determine the potential value of this market to Bovis Lend Lease;
- determine the reasons why the local market is currently growing at an unprecedented rate, determine the types of demand and forecast the growth potential;
- define the UK tall building in a Global tall building setting;
- determine the nature and structure of the tall building industry, the business models, risk profile and its supply chain characteristics;
- consider how these factors influence the delivery of tall buildings in London to achieve the Mayor of London’s target, meet the unsatisfied demand of client's tall building requirements and aspirations;
- determine Bovis Lend Lease’s current market position, review what the competitors are doing differently, outline market opportunities and provide new data on which a Bovis Lend Lease tall building strategy can be based;
- determine typical cost and revenue generators for tall buildings;

Final object was to provide innovative data worthy of future publication. This was achieved as data from this review was further researched and refined, then used as the basis for the first published paper ‘Britain’s tall building boom: now bust?’ (Skelton, I. 2009).

Conclusion

This section of research concluded the EngD Objective 1 ‘Undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors.'
4.5 FOCUS GROUP AND QUESTIONNAIRE DESIGN

The research then moved on to fulfilling Stage 1, Objective 2, Focal Theory - establishing the key international ‘wins’ & ‘losses’ on tall building projects.

A working list of tall building project ‘key issues’ had been generated by the RE during the Literature Review stage of the Doctorate. This long list was then distilled by conducting a series of semi-structured interviews with a Focus Group of four tall building project construction Company Directors, one of which was internal to BLL. This group were selected by the RE from the industry recognised major project experts and Directors of construction companies who fulfilled the following three criteria:

- The construction company (of which they were a Director) had completed in the last year, or were currently building a tall building, as defined in the RE’s 1st published paper (Appendix A);
- The construction company was in the Top 10 of the Construction News Contracts League, Commercial Contractors (excl. Retail) Jan 2006 – Jan 2007 (Fig 7 Appendix D);
- The construction company had current international major project experience.

Two sets of these interviews were held. The first was predominantly information gathering, whereby the original RE-generated long-list of key issues was openly discussed in light of each Focus Group Director’s recent tall building experience. Initially, this grew the list substantially, however after the RE analysed all issues raised in this first round of interviews, it became clear there were five common topics that covered the majority of the issues raised by the focus group. This rationalisation and refinement of the issues provided clarity and flow, whilst preventing overlap and reiteration and were used to form the key sections of the questionnaire, designed to allow an accurate snap-shot of the international tall building industry to be taken.

The RE conducted a literature review of questionnaire survey design theory, then utilised the refined tall building key issues list (cross checked to ensure the Objective Two requirements were being met) to developing a draft ‘State-of-the-Art of Building Tall’ questionnaire. This draft questionnaire was reviewed with each of the Focus Group Directors and refined further to ensure that the layout and questions were clear, unambiguous, whilst capturing the critical information needed in a form that would allow rational scoring and meaningful analysis of the results.

A Pilot Test was then conducted with ten tall building specialists, two from each of the five key disciplines to be ultimately targeted in the formal questionnaire issue. These disciplines were: End User or Client; Investor or Developer; Design Team member or Consultant; Specialist Contractor or Supplier; Main Contractor. Overall, the Pilot Test was considered successful, with a few layout refinements made to make the questionnaire more interesting, presentable and to enable the topics to flow. Relatively easy questions were presented first to engage the respondent without over taxing them, followed by the more complex, open ended questions toward the end, hence increasing the likely response rate. The pilot test also showed that a fuller and more considered response was obtained if the questionnaire was issued personally by the RE and if the intent of the background research (to which the questionnaire responses would form a key part) was given by the RE.
A cover letter was written that aimed to motivate respondents in the same way as the face-to-face discussion had in the pilot test, whilst also reassuring respondent’s confidentiality. It also gave clear instructions on how to complete the questionnaire and advised that the targeted 10 minute completion time was achieved in 50% of the pilot test cases.

The final questionnaire was designed to have a mixture of quantitative and qualitative questions. The quantitative sections were designed with a 5 point Likert method, ensuring the more difficult questions could be answered with a ‘don’t know’ rather than missed out, giving a more analytical response. Scoring of the rated questions utilised the System Usability Scale (Brooke, 1986). The qualitative questions were open ended, but gave clear description, definition, and contextual framing for the responses required.

The five key areas captured in the survey were:

1. The current state-of-the-art of the international tall building industry, containing 11 rated questions;
2. The build process of a tall building, containing 3 rated questions and 1 question rating a list of 11 risk elements;
3. The tall building principal contractor key features/issues, containing 8 rated questions;
4. ‘Wins’ and ‘Losses’ inherent with past tall building projects. This was an open ended question asking the respondent to describe their personal experience of a memorable ‘win’ and ‘loss’ on a tall building project they were involved in. These could be from any project phase from detailed design development, through construction to completion, handover and occupancy of the building. ‘Wins’ were defined as things that were done well on a tall building project that significantly contributed to the success of the construction process. ‘Losses’ were defined as things that were not done well on a tall building project that negatively contributed to the construction process.
5. New techniques from overseas and other industries, an open question asking the respondent to describe any ideas, new techniques or practices they have seen that could be adopted in the construction process of a tall building project. These ideas could be from overseas construction methods, other industry practices or just areas where the traditional building approach seems outdated and in need of a fresh approach. They could cover any project phase from detailed design development, through construction to completion, handover and occupancy of the building;

The final section asked for respondent’s details, including their tall building project name, professional discipline and contact details, to enable analysis of the results gained by discipline, geographical location and the ability for the RE to follow up on tardy responses.

The final questionnaire issued at the CTBUH Tall Building Conference in Dubai is enclosed in Appendix F. Lightly amended versions of this questionnaire were issued at the other tall building conferences as discussed below.
Questionnaire Sampling

The questionnaire was targeted at a Purposive Sample, hand-picked because they were likely to produce best specialist data. The sample selected were the most active tall building professionals around the globe (defined as either most prolific in quantum of tall building work undertaken (determined by the research undertaken in the Literature Review), or as in attending or presenting at numerous international tall building conferences). The sample selection initially started with BLL tall building project professional contacts in Asia, Australia, North America, Europe, the Middle East and Europe. This was then supplemented by adding the most prolific professionals gathered from the Tall Building Project list complied as part of the Literature Review and updated to include additional tall buildings having been subsequently submitted for planning approval since the Literature Review was conducted. This sample was then supplemented by the RE hand-issuing the questionnaire to targeted professionals attending the Council of Tall Buildings and Urban Habitat (CTBUH) 8th World Congress, held in March 2008 in Dubai. The majority of the completed responses were returned direct to the RE on day two of the conference. This very successful ‘direct approach’ was repeated at the New Civil Engineer’s ‘Engineering Tall Buildings September 2008 Conference’, held in London. Subsequently, the CTBUH expressed great interest in the Engineering Doctorate and its questionnaire topic and invited the RE to have it published on the American Council on Tall Buildings and Urban Habitat website:
http://www.ctbuh.org/Research/Overview/Constructionquestionnaire/tabid/454/Default.aspx. The research was also featured in the global CTBUH Tall Building Newsletter, May 2008 which generated additional responses.

This targeted, direct approach ultimately achieved an excellent response rate of 80% overall, yielding just over 150 valid, completed responses. This compares very well to the accepted ‘normal’ response rate of 20-30% for questionnaire surveys in the construction industry (Akintoye. 2000). This favourable response rate is thought to be due to the direct and targeted approach to the ‘most active’ tall building professionals around the world who are a surprisingly enthusiastic and proactive group that are very willing to share their specialist knowledge. The results gained from the questionnaire responses are presented in Chapter 5 and formed the basis for the second published paper ‘The State-of-the-Art of Building Tall’ (Appendix B).

One of the most interesting aspects of the questionnaire design was the many and varied responses received to the open ended questions. These gave an insight from viewpoints of the different disciplined professionals in the international tall building industry. One of the most ‘cutting edge’ and relevant responses to the EngD topic that resulted from this open ended approach was from the Project Director of Emaar Properties, Mr Greg Sang, who was responsible for the delivery of the Burj Dubai (now renamed Burj Kalif). His tall building project ‘win’ was the successful use of a super plasticised, high strength concrete which was specifically developed for the project to solve the requirement to be pumped into place up to 600m above ground via specially designed and built high-power and capacity concrete pumps situated at ground level. Mr Sang noted on his response “If steel had been selected as the structural frame for the building, it would have meant a total reliance on tower cranes to lift the steel members into position during the programme critical superstructure build. I don’t think that we could have built this building as fast if it had been built from steel because of the danger of the cranes not being able to operate because of the wind.” Thus, the man in charge of the world record breaking tall building project gave the RE further motivation to prove the idea of the Lifting Wing in combatting the effect of wind.
Analysis Undertaken

The results obtained from around the world were checked to ensure they were valid responses, then were recorded on a spreadsheet split per geographical area and professional discipline. Each quantitative question was scored utilising the SUS method as described in Paper 2, Appendix B and summarised below, allowing analysis of results for each quantitative question by respondent’s professional discipline and geographical region to allow ranking and to determine any significant variance in opinion due to either.

Qualitative questions on wins and losses were analysed across geography and discipline to determine any significant patterns.

The results from each of the five key sections reflecting the five common topics selected for investigation to capture the international tall building picture are described below. A summary representation of the 151 valid questionnaire responses is included in brackets for each question. This is shown as the median value of the responses, giving the central tendency and was calculated by ranking the selected response number for each question in ascending order and finding the mid-point response, thereby reducing the effect of extremes in distribution given by a radical or potentially ‘error’ response (Hogg, 2012). The percentage of respondents who actually selected the median answer is shown in brackets. The evaluated median results are also shown on the completed Innovation In Tall Building Construction Questionnaire in Appendix F. These results, the discussion and conclusions drawn are detailed in the second published paper in Appendix B.

Section 1. International Tall Building Industry – Current State-of-the-Art

This section set out to establish an overview of the tall building industry across the globe and the key issues inherent in building tall buildings.

Analysis of the results from this section showed that the majority of respondents from all specialist sectors and locations believe that the international construction industry was not keeping pace with the latest, cutting edge design developments in tall buildings (93 of 151 valid responses = 62%) and that the UK construction industry was perceived as not keeping pace with overseas construction industry developments (77 of 151 responses = 51%).

The UAE was perceived as the most innovative construction industry, followed by China, the USA, Japan, Australia and the UK joint fifth, followed by Korea.

It was widely believed that the global demand for tall buildings would continue to grow (81%) and that the ‘iconic’ tall building form would take over in popularity and frequency from the more traditional, rectilinear form (78%).

It was also the consensus that the tall building format provides a sustainable future for the growing global population (44%) and that the sustainability or ‘green image’ of a tall building is growing in importance (42%).

It was most commonly believed that the sustainability of the construction process of a tall building is not as important as that of the finished building (51%), probably due to the relatively short period for construction as opposed to the long operational life span of a tall building.
From a safety perspective, the majority of respondents believed that safety was of paramount importance in the construction of tall buildings (88%). Falls from height were recognised as a large contributor to health and safety incidents in the construction of tall buildings (62%), which correlates to the RE’s sponsor company HS&E records from monthly tall building safety inspections.

There was a strongly held belief (86%) that a more innovative build approach should be sought to minimise falls from heights during the build process. This was directly tackled by one of the two innovations developed during the EngD – the Mag Spanner, discussed in later in this chapter.

Section 2. The Build Process of a Tall Building

This section investigated the build process of a tall building, wherein respondents rated fourteen risks inherent with a tall building project. These results were then analysed to produce a ranking of tall building risks.

This showed that across all geographies and disciplines ‘Principal Contractor staff experience’, ‘inclement weather (winding-off tower cranes)’, ‘specialist trade procurement’ and ‘defects completion and handover for progressive occupation’ were consistently ranked the highest risk (76%). Ranked second were ‘logistical problems (man and material access, hoist / crane strategies)’, ‘superstructure cycle times / speed of erection’, ‘façade installation’, ‘services installation / commissioning’ risks (72%). The third ranked risks were ‘lift installation / builders use / commissioning’, ‘roof / waterproofing / cleaning / specialist architectural features’, ‘shell & core interface with fit-out works’ (60%). Interestingly, the lowest ranked risks for the tall build process were perceived by a small majority (46%) as ‘demolition of existing building / site clearance’, ‘ground conditions / foundations’, followed by ‘substructure construction’, which in traditional (low rise) building industry is generally considered as one of the highest construction risks.

This section also investigated the respondent’s desire for innovation in tall building construction and their experience of structural frame build speeds, a critical-path activity of every tall building. The results concluded that the majority of respondents (84%) would strongly embrace and promote innovative construction approach on their tall building project, above a tried and tested construction technique (the example given was the potential use of an innovative crane lifting device reducing the effect of wind on material lifts which, at the stage of the research, one of several innovations being considered as the final focus for the EngD research).

Section 3. Tall Building Principal Contractors

This section investigated the tall building Principal Contractor (PC), wherein respondents rated statements regarding experiences of procuring a tall building project PC, the perceived inherent benefits and most desired attributes.

The results showed that the majority of respondents across geographical and disciplinary spread believed that: Tall building PC offer a poor level of safety analysis and value analysis (buildability) of the design at preconstruction stage (63%). This was contrary to the widely held belief that involving the PC at an early stage in the tall building design does assists in delivering value, safety, programme and cost certainty (76%).

It was common across all geography’s that the procurement route options are severely restricted on tall buildings due to the limited number of high quality, capable PC’s (81%) – clearly a global short supply in times of
construction boom. Construction Management form of contract was the highest rated procurement route for a tall building PC (53%) and it was widely believe this form would continue to grow in favour.

The vast majority of professional disciplines were unanimous in the belief that previous tall building experience is critical in the selection process of a principal contractor for a tall building project (88%).

This section also showed that Construction Management and Two Stage Lump Sum forms of contract were the two most widely used forms to enter in contract with the tall building principal contractor on the respondents ‘live’ tall building projects (41%), but discussions with some of the respondents showed that the Two Stage approach was less favoured by the PC in times of construction boom when they were more in demand as this form held higher inherent risks.

Respondents were then asked to rate the importance of nine inherent tall building project risks previously disseminated from the structured interviews held with the four most prolific tall building PC’s in the UK. The results showed that the majority of respondents across both geographical and disciplinary spread believed that ‘securing finance’, ‘construction programme surety’ and ‘cost control / certainty’ were the three highest rated risks (70%). These were followed by ‘the design process meeting expectation’, ‘securing tenant pre-lets’, ‘build quality’ and ‘construction safety’ (64%). The lowest risks were seen as ‘declining demand for tall buildings’ and ‘regulatory and statutory requirements’ (60%).

Respondents were then asked to rate the importance of PC key attributes that they would consider in selecting the PC for their tall building project. The most important attribute was the ‘provision of an experienced tall building team’ (82%), followed by ‘lowest cost’, ‘innovative build approach’, ‘history of programme certainty’, ‘logistics management efficiency’, ‘procurement expertise’ and ‘local knowledge and experience’ (58%). Mid-rated attributes included ‘history of cost certainty’, ‘design management ability’ and ‘value management ability’ (55%). Lower rated attributes included ‘safety record’, ‘established supply chain’, ‘political connections’ and ‘rank or position held in the construction industry’ (58%). The least important attribute was the ‘ability to offer project funding’ (72%).

Section 4. Wins and Losses Inherent with Building Tall

The fourth part investigated respondent’s qualitative responses on experiences of tall building project ‘wins’ or ‘losses’. ‘Wins’ were defined as things that were done well on a tall building project that significantly contributed to the success of the construction process. ‘Losses’ were defined as things that were not done well on a tall building project that negatively contributed to the construction process.

This open ended qualitative section was more demanding for the respondents to complete and therefore received a lower response rate than the quantitative sections. 20% of the respondents did not fully complete this section. However, of the 80% completed, the qualitative responses were highly varied. On analysis, responses across all geographies and disciplines could be categorised into: management techniques or systems; technological advances such as innovative material or methods; perceived skills of the tall building project team; or design related wins and losses.

Perhaps unsurprisingly by discipline, Architects most frequently listed design related wins and losses, PC’s most frequently discussed management techniques and technological methods. Clients most frequently noted the skill (or lack) of the PC.
When analysed across all disciplines and geography, the majority of both wins and losses related to the perceived skills of the tall building project team.

The highest ranked tall building project win was regarding a high quality construction and management team, with tall building experience from around the globe. The second ranked win was related to the early involvement of key trade contractors or specialist suppliers, positively influencing the cost, buildability and hence programme surety. Third ranked win was related to good and consistent team communication on project issues such as cost, programme and design drivers.

Five recurring types of innovative construction methods were also captured, including slip-form advances, tower-crane and hoist advances (all from the UAE region), concrete related advances (from three different discipline members the Burj Project Team based in the UAE) and delivery phasing or staging related advances (from Australia, USA and UK). The majority of these technological wins came from respondents across the five specialist sectors who were directly involved with super-tall towers in the UAE.

The highest ranked tall building project loss was regarding a perceived low quality construction and management team, lacking tall building experience and skills. Second highest ranked loss was related to weaknesses or specific area where mistakes had been made including: poor management of the design team; poor trade contractor and supplier procurement; underestimating cost (inadequate budget), excessive design complexity and delayed programme; lack of understanding of efficient construction methods and techniques (relying on trade contractor knowledge, rather than in-house expertise). There was no perceivable pattern on either geographical or disciplinary spread or than the focus on technological advancement in UAE driven by the Burj project team responses.

Section 5. New Techniques from Overseas or Other Industries

This section investigated new or innovative techniques or practices witnessed by the respondents, which could be adopted in the construction process of a tall building project. These were described in the questionnaire as potentially being either from overseas construction methods, other industry practices, or simply areas where the traditional building approach seems outdated and in need of a fresh approach. Even though this section was open ended and qualitative, is was completed by just under 80% of respondents, whose observations covered a wide range of topics and aspects from each project phase from detailed design development, through construction to completion, handover and occupancy of the tall building.

A selection of the most radical and potentially most beneficial from each project phase include:

- Design development – A Dubai mixed use tall building utilised early specialist input to influence the design to incorporate a structural ‘jump start’ at Level 8. This allowed the construction works for this section of building to run early, in parallel with the lower levels, thereby reducing the overall construction programme;
- Construction and completion – the Leadenhall Building in London developed a ‘bottom-up’ demolition of the existing building to allow an early start on excavation and substructure construction directly below a huge suspended crash-deck above which the overhead demolition was proceeding;
- Handover and occupancy – An Australian residential tall building in Melbourne developed a phased completion strategy accepted by the statutory authorities. This entailed achieving early sectional
completion and owner-occupation of lower floors of the tower, whilst the construction of the frame, cladding and fit-out continued on the higher floors. This involved more costly solutions for segregation, waterproofing, mechanical and electrical services, life safety systems and the lifts to ensure each was fully functional on the lower floors whilst each system was still being installed on the higher floors, however it allowed early sectional completion and occupation, hence front end loading project cash flow and return on investment.

Section 6. Respondent’s Details

Respondent’s professional specialist sector, or discipline, within the tall building industry were categorised as a tall building: End User or Client; Investor or Developer; Design Team Member or Consultant; Specialist Contractor or Supplier; and Principal Contractor.

This also captured the type of tall building project the respondent was currently involved with, showing that the majority of respondents were working on ‘Commercial / Office’, followed by ‘Residential’, then ‘Mixed Use’ tall buildings. It also captured the respondent’s geographical location, their organisation / company, and the name of their current tall building project. Although the last two sets of information remained confidential, it was relevant to note that responses were gained from specialist involved with the majority of the current set of iconic tall and super tall buildings currently under design and construction in USA, UAE, London, Paris, Italy, Vietnam, Korea, Japan, Australia and across China. This demonstrated the information gleaned was from leading professionals on the teams of the most demanding tall buildings under design and construction.

Discussion

The results gained from this questionnaire targeted at a Purposive Sample, hand-picked because they were likely to produce the best specialist data, did actually produce both a very good response rate and unique data. This data analysis created a unique snapshot of the global state-of-the-art of the tall building industry over the first to third quarters of 2008. It captured the industry’s buoyant mood and strong belief in continual growth in demand for tall buildings, especially for iconic tall buildings and its unexpected thirst for innovation in the build process over tried and tested approaches.

The results reflected the industry’s growing desire for sustainability in completed tall buildings, if not in the construction process itself. A high level of appreciation of safety risks associated with building tall was common across all industry sectors and recognition of falls from heights as a primary cause of incidents on tall buildings.

The results also showed that the industry’s leading practitioners believed that the construction industry was not keeping pace with cutting edge designs for tall buildings. This maybe reflecting a frustration on the Design Team, Consultants and Client’s perspectives that their iconic designs cannot be constructed as cheaply or quickly as more traditional rectilinear designs for tall buildings.

From a UK perspective, it highlighted some surprising results as the UK was deemed not to be keeping up with overseas construction industry developments and was ranked as joint sixth out of seven countries for an innovative approach to construction. This shows the industry as a whole and particularly the UK, needs to increase the level of innovation in the tall building construction process.
The risk that was rated the highest in the tall building process across all geographical and disciplinary sectors was the provision of experienced PC staff, showing the majority of the industry feel they are under-resourced with skilled and experienced tall building professionals. This was mirrored by responses in the PC section, where it was strongly felt that procurement route options were restricted due to the limited number of high quality, capable tall building PC’s globally. This theme was also reflected by the top rated PC attribute being ‘provision of an experienced tall building team’. Additionally, the most common tall building ‘win’ was related to a high quality construction and management team, and most common ‘loss’ was related to a poor quality construction and management team, lacking tall building experience and skills. The recurring theme of the responses throughout each section of the questionnaire point to an overheating tall building construction market during the first three quarters of 2008, with insufficient skilled resources to cover the unprecedented demand for tall buildings.

It is interesting to note that the declining demand for tall buildings was seen as the lowest of nine tall building risks across all industry sectors and geographic locations. Clearly, in the first to third quarters of 2008, the industry specialists did not foresee the Skyscraper Index (Lawrence 1999) about to bite. This infamous index historically demonstrates that tall building construction follows the peak of a country’s economic cycle and is followed by a significant economic slump.

Conclusion

The questionnaire was designed to corral the views of a wide spread of specialists within the tall building sector of the construction industry and determine the state of the art of building tall. This was achieved through focus group research and targeted (and mostly direct face to face) issue of the questionnaire by the RE to the top tall building industry specialists. It resulted in an unprecedented response rate and allowed the best possible specialist data to be captured. This data was analysed to satisfy the objectives of investigating the five key areas of the global tall building industry across geographical and disciplinary spread, providing a snap shot of the state of the art of building tall. This concluded the Focal Theory section of the EngD research which was categorised as capturing ‘Key Tall Building ‘Wins’ and ‘Losses’.

The final object of this stage of the EngD research was to provide innovative data worthy of publication. This element of research formed the basis for the second published paper ‘The State-of-the-Art of Building Tall’ (Skelton, I. 2009) and provided direction for Stage 2 of the EngD research, consisting of two research steps. The first of these is Data Theory – ‘Focusing on a solution to one common and critical ‘Loss’ with theoretical research’, followed by the New Contribution step – ‘Testing and proving the innovation’, discussed in the following section.

This concluded Stage 1, Objective 2 of the EngD – ‘to capture and analyse international survey information from Tall Building experts to determine key ‘wins’ & ‘losses’ on tall building projects’.
4.6 INNOVATION FOR SINGLE CRITICAL ‘LOSS’

The research then commenced on Stage 2, focusing in on a single critical and common tall building ‘loss’ and developing a theoretical solution (Data Theory). Once this was established, the research moved on to proving the theoretically developed solution by undertaking innovative research and experimentation (New Contribution). This stage of research fulfilled Objective 3, to ‘develop an innovative solution to a critical and common key tall building project ‘loss’.

Findings from the earlier research, presented in Chapter 5 and summarised in the second published paper (Appendix B), determined that one of the two most common, critical losses on tall building projects was the detrimental effect of wind on the construction process of a tall building (the other being lack of skill levels and tall building experience of the project staff, an area warranting further research, but ultimately not selected by the RE due to a high level of personal interest in the more technical challenge set by the wind effect). The criticality of the wind effect was distilled from the following three key results:

- ‘Inclement weather (winding-off tower cranes)’, consistently ranked one of the two highest construction risks, followed by ‘logistical problems (man and material access via hoist and crane)’, ‘superstructure cycle times / speed of erection’ and ‘façade installation’, all directly related to wind and its effect on the tower crane;
- Tall building experts believe ‘construction programme surety’ and ‘cost certainty’ were the two most significant risks to a tall build. The most important attribute of principal contractor was determined as ‘innovative build approach and the provision of an experienced tall building team’, followed by ‘history of programme certainty’, ‘logistics management efficiency’, reinforcing the industry’s thirst for innovation, desire for logistical, programme and therefore cost certainty;
- 84% of tall building experts interviewed confirmed they would strongly embrace and promote the use of an innovative construction technique that reduces the effect of wind on tower crane material lifts on their tall building project.

The conclusion of this stage of the research was that there was strong international desire for an innovative solution to critical construction problems, the most highly ranked of which was wind negatively affecting the build. Paired with the highest ranked desire of programme certainly and hence cost certainty, this signposted that an innovative concept was needed to mitigate delays to the tall building programme duration by reducing the effect of wind on the critical path activities of the tower crane. This focused the final ‘new contribution’ part of the research on testing and proving an innovative concept, subsequently named the ‘Lifting Wing’, aimed at directly addressing this global industry need.
Hypothesis

The Lifting Wing takes design inspiration from airships of old and applies this aerodynamic engineering concept to the actual building of a tall building and its crucial construction device, the tower crane.

Conclusions from the earlier published paper (Skelton 2009), along with research undertaken in aerodynamic theory reinforced by the RE’s own observations of the effect of wind force on a suspended load of a tower crane, led to the idea of reducing the effect of this force by sheathing construction materials in an aerodynamic profile during lifting operations. The RE hypothesised that a specifically designed aerodynamic shroud may reduce the wind force effect on a typical construction load, creating more stable flight characteristics and ultimately reducing the loads imposed on a tower crane, thereby increasing the ability to lift safely in challenging wind conditions.

Various profiles were investigated to achieve the best compromise of two diametrically opposed requirements; that of an aerodynamic shape and the ability to allow large and irregular shaped construction materials to be encapsulated within the aerodynamic profile. The cross section of an aerofoil (a two dimensional wing) rotated to a horizontal orientation was eventually selected by the RE as most suitable due to established aerodynamic research showing that at low approach angles, air flow is able to follow the curve of the upper and lower surfaces of the aerofoil closely, then join smoothly towards the trailing edge, minimising eddies (Anderson 2010).

A summary of the key research undertaken into the effect of wind on tower cranes, their height, location, proximity of other tall buildings and most importantly their loads, are presented in the following section of work.
The Theory of Wind Effect on Tower Cranes

Wind forces exerted on the lattice structure of a tower crane and the construction load suspended from it, directly affect the ability to safely operate and control a crane and its load. The higher the wind speed, the greater the force exerted on the crane and load. This force is wind pressure, caused by gas molecules that make up the airstream moving with a velocity and gaining Kinetic Energy as the velocity increases. When these molecules meet a relatively fixed surface, they are slowed or stopped and the energy of the molecules is transferred into wind pressure or force per unit area. The relationship between wind pressure (p) and wind speed (vs) is \( p = K v^2 \)

where \( K \) is a factor related to the density of air, which for design purposes is assumed to be constant. Where the wind pressure (p) is in N/m\(^2\) and wind speed (vs) in m/s, \( K \) is 0.613, giving \( p=0.613 \) vs\(^2\) (Allen, 1999). This squared relationship between wind speed and wind pressure means that a relatively small increase in wind speed can have a significant effect on the wind force and hence the stability of a crane and its load.

From the RE’s experience as Project Director on many construction site utilising tower cranes, it was known that the manufacturer of each tower crane specifies a maximum theoretical wind speed at which their tower crane should be taken out of service. In high wind speed conditions experienced on a construction site, the Tower Crane Operator (crane driver) has the responsibility to decide to take the crane out of service due high wind. This generally happens at a wind speed significantly lower that the manufacturers prescribed ‘out of service’ speed, due to the driver’s increased difficulty in safely controlling the crane. This is primarily due to the effect of the wind pressure on the construction load being lifted, rather than the crane structure itself. The wind pressure acting on the load suspended at the end of the tower crane lifting cable results in increasing difficulty for the operator controlling the crane’s operations of lift, swing, travel, lowering and landing of loads in a congested construction site teaming with construction operatives. This causes a significant safety risk, not only the crane operator, but to anyone in the vicinity of the crane and its load, hence the crane is taken out of service.

In the UK, the Tower Crane Operator has the primary responsibility for making the decision to cease lifting operations and put the crane out of service, in conjunction with the Appointed Person or Crane Supervisor. This decision is subjective, but would very rarely be overridden by site management due to safety concerns, even though the management’s primary interest is the continued operation of the tower crane to ensure the tall building progress continues, programme does not suffer and that substantial costs are not incurred.

The currently accepted norm for tower crane inactivity or ‘down time’ due to high winds in the UK construction industry is 40% over the life of the project (CPA 2008). For a typical tall building project constructed over 3 years (150 working weeks), a tower crane is on the critical path of the construction project for circa 100 weeks whilst demolition, excavation, foundations, structural frame, possibly cladding, and roof top equipment are constructed. A 40% downtime over this period equates to programme loss of 40 working weeks, or almost 1 year. Any improvement on this would clearly save substantial time on the critical path of a tall building construction programme and hence save substantial costs. ‘Winding off’ is the construction industry term used to
describe when the wind speed is so high it makes the load on a tower crane unstable and act unpredictably, or the driver feels uncomfortable with the risk of continuing. Research was undertaken by the RE as part of this EngD on four BLL UK tall building projects. This showed that the tower cranes on a tall building site are, on average, winded off at wind speeds less than half that specified by the crane manufacturer as the maximum speed operationally permissible. This obviously have very costly implications on the project programme and finance.

Long range weather forecasts indicate the UK climate is getting more adverse with higher wind speeds expected to occur more regularly over more months (Met Office 2014), which will exacerbate tower crane average down time on tall buildings, lengthening programme and increasing build costs. Clearly, a technique or method to reduce or mitigate the effect of high wind speed on the construction of tall buildings would be extremely beneficial.

Wind Effect on Suspended Loads

Meteorology shows that strong winds have a tendency to gust rather than blow consistently. This is amplified in tall building construction site locations, which are generally in or adjacent to built-up clusters in city centres. The existing neighbouring buildings break up the relatively smooth flow that wind would achieve over open land and cause turbulent layers in the flow, resulting in large eddies. Aerodynamic theory calls this separated flow and it causes a mix of high pressure in clear space and low pressure behind neighbouring buildings (Anderson 2010). This separated flow of air across a construction load suspended from a tower crane results in a swinging motion of the load, pushing it out of balance and increasing the radius from the load’s centre of gravity to the tower crane mast, increasing the turning moment and potentially making the tower crane unstable. For relatively light loads with a large surface area, such as plywood shutters of formwork for concrete frame buildings, steel floor pans for steel frame buildings or cladding panels, this situation will occur significantly below the tower crane’s design wind speed. This is demonstrated below:

At wind speed of 14m/s (30mph), the wind load on an 2.5m x 1.3m (8ft x 4ft) standard formwork shutter is 375 Newtons (N). If the wind speed increases by 50% to 20 m/s (45 mph), the wind load rises to 740 N, almost 100% increase in load. If the wind blows from behind the crane, the load radius will be significantly increased, potentially overloading the crane. For example, a formwork shutter weighing 750kg with an area of 3.25m2 and suspended on a 27m hoist rope will move 1.4m from the vertical when subjected to a 14m/s (30mph) wind. Moving the load radius by this distance on a 35 tonne capacity crane with a 34m main boom working at 18m radius would reduce the rated capacity of the crane from 950kg to 640kg. If this occurs close to the lifting and radius limit of a tower crane, the result could be a catastrophic crane collapse.

This effect has caused the failure of many tower cranes, the most famous of these being ‘Big Blue’. The concluding independent report is extracted below:
‘On July 14, 1999, while lifting a section of the retractable roof for the Milwaukee Brewers new stadium, the Lampson Transi-Lift crane nicknamed 'Big Blue' suddenly collapsed. As a result of the collapse, three workers died, five more were injured and the opening of Miller Park was delayed for a season. The litigation stemming from this accident has resulted in sizable monetary penalties. Directly following the collapse, a number of theories were offered as possible reasons for the failure, including faulty crane parts, poor soil conditions under the crane and wind loads on the crane. The crane had a rated capacity of 1500 tonnes and was lifting a load of 450 tonne, well inside its maximum capacity. Upon investigation by independent specialist bodies, the conclusion was that the primary factor of the collapse was the high wind load acting on the section of roof being lifted and lack of consideration of those loads on the crane's rated capacity’. (Riewestahl 2010)

Large structures such as the ill-fated roof panel at Miller Park should not be lifted by cranes in winds of 20 to 32mph, according to the crane accident investigators (OSHA 1999). The wind loads on the day of the failure along with the failure of the people responsible for the lift to account for such wind loads were at the heart of the collapse of Big Blue. Wind speeds taken at various sites around the Milwaukee area varied in measurements at the time of the failure, but an average wind speed was concluded to be 23mph with gusts up to 35mph (Ross 2006). However, the crane's anemometer was located only 180 feet above ground and recorded wind speeds topping out at 20mph, but the top of the crane was actually at 530 feet above ground. The winds at higher elevations above grade were so noticeable on the day of the failure that group of ironworkers left the job site around noon refusing to work at elevation due to concern over their personal safety (Ross 2006). During the investigation it was found two monitoring devices on the crane that were designed to trigger an alarm if the wind speeds were excessive or the load was off balance, were found to have dead batteries.
Height effect on Wind Speed

It is established practice in the UK construction industry that tower crane lifting operations should be planned in advance and anticipate wind speeds from site specific weather forecasts to ensure that lifts are not started in rising wind speeds. In the UK weather forecast wind speeds are given for a typical height of 10m above ground and must be corrected for the additional height of a tower crane. In open countryside, wind speed increases with height by a factor of 1.39 at 100m above ground and 1.47 at 150m above ground. In city centre locations the gust wind speed at a height of 100m will be approximately twice the gust wind speed at pedestrian level. Nearby buildings can have a significant influence on wind forces, if they are the same height as the crane, they may provide an element of shelter, or channel and increase the wind speed depending on their layout in relation the wind path and tower crane. If surrounding buildings are significantly taller, they may funnel the wind and generate increased wind loading on tower cranes and their suspended loads.

The force exerted by wind on a tower crane structure is the wind pressure multiplied by the surface area of the structure. This force acts at the centre of an area, or centre of pressure of the crane structure and creates an overturning moment, calculated as the wind force multiplied by the distance from the centre of the crane to the ground. The greater the distance between the ground and the centre of pressure, the greater the overturning moment. These effects result in a doubling effect for very tall cranes commonly used to construct tall buildings.

High Wind Conditions Taking a Tower Crane Out of Service

It is clearly important that the crane operator constantly monitors the wind speed using the anemometer display in the cab to give an early warning of rising wind speeds and give enough time to take the tower crane out of service and descend the tower whilst still safe.

Tower cranes are designed to international standards that specify the ‘in-service’ wind speed that a crane must be able to withstand and operate safely. These are typically 14m/s (31mph) for mobile cranes, 20m/s (45mph) for tower cranes and 28.5m/s (64mph) for dockside and container cranes. In addition, the standards specify the ‘out of service’ wind speeds for those cranes which cannot be easily lowered to the ground such as tower, dock and offshore cranes. These wind speeds are typically 36m/s (80mph) onshore and 44m/s (98mph) offshore.

Putting a crane ‘out of service’ includes ensuring that the crane jib is free to rotate or ‘weather vane’, to ensure the minimum surface area of the crane is presented to the prevailing wind. This theory has been utilised in the design of the Lifting Wing which also presents the minimum surface area to the prevailing wind.

Aerodynamic Theory Shaping the Lifting Wing

Wind force on a particular crane can be calculated by multiplying the pressure by the area of the parts of the crane structure exposed to the wind. A crane structure is made up of many components of different shapes and sizes, each having a different surface area, resistance to the wind and hence wind load. Each differently shaped
component is assessed separately, with its area square to the wind being multiplied by the appropriate force coefficient (Cf). This process is covered in detail in the International Standard ISO 4302-1981 Cranes – Wind Load Assessment.

The wind force on a construction load suspended from a tower crane is simpler to calculate, but as previously described has a more dramatic effect. A streamline flow of air past a flat sheet section (such as a section of formwork, steel floor pan, or cladding panel) perpendicular to the direction of the prevailing wind is shown in the diagram below. In front of the sheet, the air separates to move around it. Approximately half the flow goes above the sheet and half below. Along the centre of the sheet, there is a stagnation point as the air is forced to stop, resulting in the separation streamlines.

According to Bernoulli's theory (Kermode 2012), when air is slowed down its pressure increases, and vice-versa. As the air comes to a stop at the stagnation point, it creates a high pressure region ahead of the sheet, pushing it backwards. Behind the sheet the air is not able to closely follow the surface of the sheet and so large eddies form. This separated flow creates a low pressure region behind the sheet, literally sucking it backwards.

![Resistances](image)

**Figure 4-5. Flat Section Separated Flow (Kermode 2012).**

This flat sheet section is the most common shape for construction materials regularly lifted by a tower crane. A cylinder shape is also commonly lifted (concrete kibble, column sections, moulds, cylinders, pipe sections, bundled services and any loose materials contained in a drum). The flow of air around a cylinder is shown below:

![Resistances](image)

**Figure 4-6. Cylinder Section Separated Flow (Kermode 2012).**

The high pressure in front of the cylinder and low pressure behind is similar to the flat sheet, but less dramatic as the air flow follows the curve of the cylinder more closely before becoming separated, or eddying. The low pressure behind the cylinder is not as low as behind the flat sheet, resulting in a resistance of approximately half that of the flat sheet.
This theory led to the RE’s idea of reducing this resistance further by lifting construction materials encapsulated in the most aerodynamically efficient shaped profile to minimise the resistance or wind force effect on a tower crane and its load.

The section of an aerofoil (a two dimensional wing) is shown below. It can be seen that the air flow is able to follow the curve of the upper and lower surfaces of the foil very closely and join smoothly towards the trailing edge, minimising eddies. There is still a high pressure region at the front, but the low pressure at the rear is much closer to atmospheric pressure. This results in a resistance that is around twenty times less than the flat sheet and ten times less than the cylinder.

As an aerodynamic ideal, the Lifting Wing design would follow a slim, streamlined aerofoil profile with a sharp trailing edge. However, the practical consideration of ensuring typically large construction loads can be accommodated inside the profile outweighs the desire to reduce the drag to an absolute minimum level. This results in an aerofoil profile that is wider than the ideal, but still aerodynamically efficient.

**NACA Foil Design**

The National Advisory Committee for Aeronautics (NACA) conducted extensive research into aerofoils from the 1930’s, some of which are still utilised in aircraft manufacturing and are defined by four-digit wing sections:

- The first digit describes the maximum camber as percentage of the chord (the line between the leading and trailing edges);
- The second digit describes the distance of maximum camber from the aerofoil leading edge in tens of percent of the chord;
- The third and fourth digits describe the maximum width of the aerofoil as percent of the chord.

Mathematical analysis of the typical NACA profile is widely accepted aerodynamic theory and was not needed to be repeated in this Thesis. The XFOIL programme (Drela 1989) was utilised to review 2D aerofoils between NACA 0012 – 50 to determine the most suitable profile that when extrapolated into a 3D shape would achieve a balance between aerodynamic efficiency and sufficient width to accommodate an array of typical construction load dimensions.
NACA 0035 (00 indicating that it has no camber, 35 indicating that the aerofoil has a 35% width to chord length ratio) was ultimately selected as the aerofoil profile most suitable for the Lifting Wing design, balancing length and width to accommodate the largest, most commonly lifted tall building construction loads. An analysis was undertaken of materials most commonly lifted in the construction of a typical concrete and steel framed tall buildings. This analysis showed that metal floor pans or decking used as permanent formwork for concrete floors in the majority of steel framed tall buildings, plus timber formwork, bundles of structural steel, reinforcement or concrete planks for concrete framed tall buildings (both circa 1.2m wide up to 4.5m long) can be inserted within the profile which would have a chord length of 6m at full scale. The selected profile would also comfortably accommodate typical individual or loose loads such mechanical and electrical services components, concrete kibbles and skips, edge protection screens, and palletised or bagged loads such as blocks, sand & cement. At full scale, the selected profile would accommodate these most commonly lifted items, whilst offering a relatively narrow frontal area, smooth flow path around the flanks to minimise flow separation and a sharp trailing edge to minimise drag and side forces otherwise exerted on the load and transferred to the crane.

The Lifting Wing

The full scale Lifting Wing described by the NACA 0035 aerodynamic profile would be 6m long x 2.16 m wide by 2.0m high, built of a lightweight, high impact resistant clear plastic skin over a stiff, skeletal frame. It would be open at the top and bottom to allow it to be lowered over the load and for access to the lifting chains. It will be hung with 3 point lifting chains attached to the crane hook and lowered by crane over the construction materials to be lifted. The load would then be propped or strapped inside the Wing, restraining the load’s position relative to the Wing. The Wing would fully encapsulate the load, which is then directly suspended from the hook of the tower crane. The Wing profile thereby gives the load an aerodynamically efficient, predictable and more controllable profile in high wind speeds. A smaller version could also be made to accommodate smaller loads such as palletised and bagged loads, 3m long and 1.5m high. A bigger version could also be created for special loads such as cladding elements, external architectural features or roof mounted service equipment.

Following established aerodynamic theory, the Wing should reduce the critical drag load (C Drag) and pitching moment (C Pitch) acting on the suspended material thereby reducing its tendency to swing fore and aft on a crane rope. The Wing should also reduce the effect side force (C Sideforce) and yaw (Yaw Angle +/-) which cause lateral oscillation of the lifted material induced by the wind forces (Wind Velocity) acting on the load being lifted. This is diagrammatically shown in Figure 4-8, below. The reduction of the effect of these wind force induced loads and the production of a more stable ‘flight’ of the lift should theoretically result in safer lifting of construction materials in higher and gustier wind-speed conditions than the current industry standard. The ultimate objective is to reduce the industry accepted norm of 40% ‘down time’ for the tower crane over the construction phase of a tall building due to ‘winding off’. This would thereby save time on the critical path of the tall building construction programme and hence, substantial costs. This hypothesis was then tested in the final
stages of the EngD research by building an accurate scale model of the Lifting Wing, specifically designed for wind tunnel testing.

Practicalities of the Lifting Wing Design

To ensure that aerodynamic theory behind the design of the Lifting Wing could translate to practical use on a construction site, an analysis was undertaken by the RE of the practicalities of using a Lifting Wing on site. Following initial research undertaken by the RE on a number of key practical, logistical and operational considerations, it was decided to reuse the focus group method of research to ensure answers determined to these key issues were derived from a cross section of experienced tall building practitioners. To this end, a second focus group was established to review the following: practicalities the Wing design; wind-off frequency; list and rank the most commonly lifted construction materials during the programme-critical tower crane dependant period of a tall building; the cost of wind related delay to a tall building project; how to build and operate the Wing; and to answer the question why this potential solution has not been produced by in the international industry to date.
The Lifting Wing Focus Group

The Focus Group methodology successfully used for the earlier stage of the EngD research was again employed in this section of the research to explore, rationalise and refine the issues of logistics and safety associated with the use of the Lifting Wing. A series of semi-structured interviews were held with a Focus Group of four Senior Construction Managers running either tall or major projects located on logistically challenging London city centre sites. A set of drawings of the Lifting Wing were produced by the RE and used to help portray to the group the intended purpose, size and shape of the Lifting Wing. These discussions provided clarity to the initial ‘long’ list of issues raised by grouping and ranking the key issues raised by the focus group. The following are the resultant key issues and potential solutions resulting from these interviews:

Initially the focus group assisted the RE analyse the ‘As-Built’ verses ‘Planned’ construction programs and the associated delay records for one of the Senior Construction Managers tall building projects – those of Bishopsgate Tower in London. These were then cross checked against similar records received from the Australian BLL business from the recently completed tall building ‘Aurora Place’ in Sydney. Analysis of results of both tall building site records showed crane wind off frequency resulting in an average down time of 42% (London tall building) and 45% (Sydney tall building) during the time period that the tower cranes were on the critical path of each project (foundations, basement, frame, cladding and roof plant). This compares with advice published by the Tower Crane Interest Group & Construction Plant-hire Association -Tower Crane Technical Information Note 27, 2009, which states that 40% down time is the industry ‘norm’ in the UK. The group concluded that wind was the most significant single source of delay to a tall building project.

The focus group then generated a table of commonly lifted construction materials during the programme-critical tower crane dependant period of a tall building, then ranked the materials from worst to best ‘handling’ in higher wind conditions. The best performing i.e. those able to be lifted in relatively high wind speeds were reinforcing or structural steel bundles concrete kibbles and pallets of blocks. The worst performing materials i.e. very susceptible to wind speed increases, were ranked as cladding panels, plywood sheeting, formwork panels, roof sheets, metal floor pans and precast floor planks. The group concluded that the Wing had to be designed to accommodate a wide range of material sizes and shapes up to circa 4.5m long and up to 2m wide.

The focus group then examined an analyses of tower crane wind-off cost that was undertaken at the BLL tall building project Bishopsgate Tower. This information was then utilised to determine the potential commercial value of the Lifting Wing saving time on the critical path of the programme (costs included direct cost, preliminaries, loss of rental income, but not the commercial penalty effect of missing the contract completion date and Liquidated and Ascertained Damages being applied). Summary results showed that savings were substantial, running into tens of thousands per lost working day on a large project such as Bishopsgate. Additionally, the Senior CM on Bishopsgate raised the previously unrecognised benefit of an increase in reputational value due to the potential ability to work on windy days when other tall building sites in the City are winded off. The group concluded this would indeed be a unique selling point to the tall building market.
The focus group then examined the possible reasons why no-one has come up with this idea before. The RE presented the market analysis previously undertaken as part of the taught element of the EngD (Surrey University Master’s Degree in Entrepreneurship), which attempted to understand why this area had not been investigated by key parties in the tall building construction industry. Each relevant sector of the market directly involved with the manufacturing, hiring, provision, and utilisation of tower cranes were discussed and analysed. Summary findings were that reducing winding off time is not in the crane manufacturers or supplier’s interests as they currently benefit from delays which result in longer hire periods, rental being paid regardless of crane utilisation. Crane drivers and ground crew are similarly are paid hourly rates or fixed salary, regardless of utilisation. Trade Contractors needing to use the crane would also potentially benefit from weather delays as this is traditionally held as a Client or Principal Contractor risk. They would simply submit delay claims and potentially benefit commercially. Only PC’s and Clients would benefit from a reduction in wind induced delay and both parties have their focus on other critical aspects of the project delivery process. These findings were agreed by the focus group as reasons why this area of innovation has not been pursued to date by any party in the construction of tall buildings.

The focus group then examined existing component technology. The material construction options potentially suitable for use in constructing the Lifting Wing were discussed, ideally satisfying the diametrically opposed needs of light weight and ability to withstand the damage from rough handling, common on construction sites. Focus group ideas included:

- Type of props to be used to restrain load inside the Wing – car boot gas struts or hydraulics with soft clamp were discussed, but simple tension straps / taught liner strops (commonly used on lorry’s to restrain loads) were favoured by the group for simplicity of operation;
- High impact plastic material for the ‘skin’ to offer light weight yet relatively indestructible characteristics needed on a typical construction site;
- Sailing industry technology – carbon fibre / Kevlar woven sail material ‘skin’ stretched over carbon fibre lattice frame would give lightest solution, but potentially may not robust enough for a site environment.

The focus group finally examined the issues of practicalities of the Wing on site. The key problem and potential topics were discussed:

- Site storage is always an issue on physically constrained construction sites. At circa 6m long x 2.5m wide, it was clear the Wing needed to be stored out of valuable and congested site space at ground level. The solution developed by the group was to design a secure fixing method to allow the Wing to be lowered and fixed to the roof of a metal site container, (commonly used for storage of site materials or as a site office) and locked securely into position, thereby taking up no room at the congested ground level of a site;
• Potentially, two different sizes of Wings could be commonly utilised; a small circa 3m long version for skips, pallets, small cladding panels and bagged or bundled materials; the 6m version for roof sheets, full height cladding panels, formwork, tables, mechanical and electrical services equipment etc.
• Transportation to and from site would be by standard articulating lorry, therefore meeting standard site logistic planning for delivery space, swept-path turning circles etc.
• To ensure safety on site the Wing would be treated as a Lifting Accessory and therefore subject to annual testing procedures to ensure all fixings used for lifting were fit for purpose.
• Build cost, commercial lifespan and whether to hire or sell Lifting Wings was studied as part of the Surry University Master’s Degree in Entrepreneurship undertaken by the RE, part of which required the development of a Business Plan, submitted as part fulfilment of the EngD Taught Element. The Plan is enclosed in Appendix E.

The focus group again proved beneficial in producing the ‘long’ list, grouping and then refining the issues. In this instance, this approach allowed the tackling of a wide range of problems associated with logistics and safety aspects of using a Lifting Wing on site. It was especially beneficial in providing a number of solutions to these issues which were outside the professional expertise of the RE and in reinforcing that the Wing was generally received as a sound concept, even at the highly practical and robust Senior Construction Manager level, a group deemed to be fundamental to the acceptance or rejection of the Lifting Wing at site level and hence, its viability.

Aerodynamic Testing of the Lifting Wing

Having completed critiquing the idea practically and against established aerodynamic theory, the next stage of research was to conduct aerodynamic testing of the Lifting Wing, with the specialist assistance of Loughborough University Aeronautical and Automotive Engineering Department. The methodology of the modelling and wind tunnel testing are presented here. The results of this stage of research are presented in Chapter 5, Findings & Implications.

CFD V’s Wind Tunnel Testing

Firstly, the two main alternative approaches of analysing aerodynamic behaviour were investigated. These methods are computational fluid dynamics (CFD) and low speed wind tunnel testing, both widely used to predict the impact of wind on buildings and their surroundings and also on automotive and aeronautical design.

A comparison of the two appraisal methods was undertaken resulting in the following summary:
### Comparison of Appraisal Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| **Wind Tunnel** | Well established and validated.  
Mainly performed by specialist contractors.  
Suitable for safety critical issues.  
Flexible – can be used for most applications.  
Numerous wind directions can be tested quickly and easily.  
Flow visualisation possible. | Relatively few suitable facilities.  
Measurements at discrete points – not the entire flow field.  
Reliable model-making may sometimes be an issue. |
| **CFD** | Can be done in-house.  
Full flow field predicted.  
Flow visualisation possible. | Not well established for wind engineering.  
Not suitable for structural studies and safety-critical issues.  
Time-averaged results only.  
Results difficult to interpret – specialist knowledge is essential.  
Reliability of results can be uncertain. |

Table 4-1. Comparison of Wind Tunnel Testing Versus CFD.

Clearly there are benefits and limitations of each method and each is more suitability for different applications. CFD is more successfully applied to predict internal flows and assess thermal comfort and air quality, but some designers require the confidence that can only be gained from full-scale mock-up testing of complex solutions. Wind tunnel testing is still probably the most appropriate tool for examining external flows around the building and its impact on surroundings (The Architect’s Journal 2002), along with automotive and low speed aeronautical applications (sub-supersonic flight). Additionally, wind tunnel testing is often preferred in early stages of design as it can provide the full complexity of real fluid flow and produce large amounts of reliable data, rapidly and accurately. Results from the use of scale models in wind tunnels have been proven to accurately predict full scale behaviour (Barlow 1999).

It was therefore determined that CFD techniques were not preferable and low speed wind tunnel testing was selected for the EngD Lifting Wing aerodynamic research.

Aerodynamic theory of low speed wind tunnel testing was then researched and that theory applied to the Lifting Wing hypothesis. The first question the RE considered was the correlation of wind tunnel to actual flight data once a model (aircraft) had been developed in to full scale. Research showed that this is a closely guarded area of data by companies. There are very few comparison studies, but the Aeronautics industry agrees that model testing use in early design stages saves both money and lives (Barlow 1999).

### Low Speed Wind Tunnel Tests and the Parameters for Similarity of the Model and Full Scale

Low speed wind tunnel tests by definition are those capable of undertaking tests of up to 300mph, or 134m/s and are based on the three fundamental principles from which equations are used to model low speed aerodynamics: Mass is conserved; Newton’s 2nd law of motion F=ma; and energy exchanges are governed by 1st law of thermodynamics (Barlow 1999).
To ensure these tests are successful, the parameters for similarity of the model and full scale must be considered. Research shows that the most important aspect for a test in which the model is held static during data gathering is:

\[
\text{Reynolds Number (Re) = Inertia Force / Viscous Force = (Density \times \text{Velocity} \times \text{Length})} / \text{Absolute Coefficient of Viscosity}
\]

If the model has the same Re as the full scale application, then they are dynamically similar. The non-dimensional functions of fluid viscosity, density, pressure coefficient and temperature will be the same for the model and full scale. In turn, the force and moment coefficients will be the same for both, therefore the forces developed by the model can be directly related to forces on the full scale Wing by multiplying the force coefficients obtained in the experiment by the factor \(\frac{1}{2} \cdot \text{p} \cdot \text{delta} \cdot \text{V}^2 \cdot \text{delta} \cdot \text{L}^2 \cdot \text{delta}\).

Similarly, the moments developed by the model can be directly related to the full scale Wing by multiplying the moment coefficients obtained in the experiment by the factor \(\frac{1}{2} \cdot \text{p} \cdot \text{delta} \cdot \text{V}^2 \cdot \text{delta} \cdot \text{L}^3 \cdot \text{delta}\).

In practice, it is acknowledged that it’s rare to match the Re for the model and full scale, so careful evaluation of the effect of the Re must be made to ensure the results can be applied to full scale. The scaleable relationship (provided that pressure and temperature are constant) is that drag coefficient on a given shape with fixed Re at full scale at 20mph = \(\frac{1}{10}\) th scale at 200mph.

**Wind Tunnel Test Design**

Established theory determines that at sea level, a tunnel must be designed to achieve the following:

\[
\text{Vdelta = circa 100m/s and Unit Reynolds No = circa 6.98x10^6 m}^{-1}
\]

It is must also be designed to capture aerodynamic changes as they are affected by a variation of Re, so useful conclusions can be drawn without duplicating the full scale Re. The ratio of the model Re to full scale should equal the size ratio of model scale to full scale.

These aspects were considered in designing the model and testing procedure utilising the Loughborough University facility. Efforts were made to mimic the true profile of the full scale Lifting Wing to allow the model Wing drag results to be extrapolated to the net Re, the results of which would only be slightly optimistic due to the drag factor of the full scale lifting block and chains that are not represented on the model.

The wind tunnel testing was designed in conjunction senior staff and technicians from Loughborough University’s Aeronautical and Automotive Engineering Department and was undertaken in the largest of their three wind tunnel facilities, the scale of which is evident from Figure 4-10, showing the Bell-mouth and Exhaust ducts. This wind tunnel has an open circuit layout and a closed working section of 1.92m wide, 1.32m high and
3.6m long. These dimensions dictated that the model had to be sized with a frontal area between 5-10% of the tunnel section area (the tunnel area is circa 2.5m sq dictating a frontal area no greater than 0.25msq) and scaled to replicate 6.0 long x 2.16 m wide by 2.0 high, whilst not exceeding 25 kg.

The tunnel working section normal operating velocity is 40m/s, with a maximum of 45m/s. This equates to a wind velocity of 100 miles per hour, utilising the conversion factor of 1mph = 0.44704m/s. Within the working section of the tunnel the underfloor, six-component balance is situated. It is shown viewed below the tunnel working section in Figure 4-11. This sophisticated device measures Drag (accuracy 0.01% of full scale), Sideforce (accuracy 0.005% of full scale), Lift (accuracy 0.01% of full scale), Roll moment (accuracy 0.01% of full scale), Pitch moment (accuracy 0.01% of full scale) and Yaw moment (accuracy 0.015% of full scale). The tunnel and its full suite of components are shown graphically in Figure 4-9.

Figure 4-9. Loughborough University Aeronautical and Automotive Engineering Open Circuit Wind Tunnel Isometric.
Figure 4-10. LU AAE Wind Tunnel Bell-mouth & Exhaust.

Figure 4-11. Six-Component Balance below Tunnel Working Section.
Test Aim and Design

The aim of the test was to compare the aerodynamic performance of the scale model of a typical rectangular, ‘brick’ shaped construction load (designed to replicate the load profile most commonly lifted via a tower crane) against the aerodynamic performance of the scale model of the Lifting Wing in a range of wind speeds and yaw angles. This would therefore determine the increased aerodynamic performance of using the Wing in a range of wind speeds and yaw angles.

The tunnel wind quantitative test results were then designed to be checked by two distinct qualitative methods of aerodynamic analysis:

- Firstly, surface flow visualisation analysis was undertaken at key stages of the wind testing allowing the wind path to be established helping to explain the results of the wind test. This method makes invisible airflow patterns visible, revealing air flow streamlines as they approach and flow across the Wing’s solid surface. A series of flow visualisation photographs of the Brick and Wing models were taken at key stages in the wind tunnel testing, allowing comparison of aerodynamic flow around the models.

- Secondly, a preliminary dynamic test was undertaken providing a real-time visual indication of the Wing’s aerodynamic characteristics under conditions reflecting, as closely as possible, suspension of the Wing from a tower crane cable in wind conditions likely to be experienced on a tall building site. No quantitative measurements could be taken during this test, purely a visual analysis of the Wing’s aerodynamic performance.

These are both discussed in more detail in the following sections.

To ensure the wind tunnel test results were predicative of full scale results, the tests were planned to be undertaken with a Reynolds number (Re) as close to the calculated full scale Wing, Re of 8.2 x106, calculated for a wind speed of 20m/s, where Re = Inertia Force / Viscous Force = (Density x Velocity x Length) / absolute coefficient of Viscosity. This would then then reflect the accepted academic theory that if the model has the same Re as the full scale application, then they are dynamically similar as the non-dimensional function of Fluid Viscosity, Density, Pressure, and Temperature are the same for the model and full scale.

To determine this for the Lifting Wing model, a number of Re sweep tests of both models were undertaken (discussed in more detail later in this Chapter). The results of these sweeps showed that Re became invariant above 1.5x106. This demonstrated that the results obtained for both models would replicate the full scale Lifting Wing in wind speeds of up to 90mph (current international standards for tower crane ‘in-service’ wind speeds with no aerodynamic aid are up to 20m/s or 45mph).
Building The Models

To undertake the planned test, two scale models had to be accurately constructed. After several attempts to construct the models using plastic sheet and dense foam with limited success, it was decided that the models would be built using a 2mm thick plywood veneer sheet forming the outer face of the models, fixed to a plywood spar frame cut utilising a computer numerical control (CNC) machine. This form of construction was inspired by the build method of acoustic guitars which have a sweeping curved form of similar radius to the planned Wing model. The Loughborough University CNC wood router machine used for the model making created the 3D frame elements from plywood using the Cartesian coordinate system (X, Y, Z) for 3D motion control. The model frame elements were firstly designed in the computer with a CAD/CAM program. This allowed these elements to be cut automatically using a routing and trimming head to produce finished parts to within 0.5mm accuracy, crucially important to ensure symmetry of the Wing model. The 2mm thick ply veneer was then bent and forming of the around the spar frame, fixed, glued, filled and sanded and sprayed matt black to complete the models.

The resultant scale model of the Lifting Wing was built to an accuracy of +/-1mm, with the design based on the NACA 0035 aerofoil. The chord length was 600mm, maximum width of 216mm and height 200mm, with a cross sectional area of 0.0432m². This equates to a 1:10 scale model of the full size Lifting Wing. It is shown below mounted on the working section of the tunnel.

Figure 4-12. Scale Model Wing Mounted on the Working Balance of the Tunnel.
Similarly, the 1:10 scale model of the typical construction load, the ‘Brick’, was built with the same tolerances, having a chord length of 600mm, maximum width of 210mm and height of 200mm, giving a reference area of 0.043m$^2$. It is shown below similarly mounted.

**Wind Tunnel Test Objective and Summary**

The objective of the wind tunnel test was to generate quantitative data for the model’s drag (Cd), lift (Cl) and pitching (Cp) moments at varying degrees of yaw and wind speed. The wind tunnel test was designed to minimise systematic errors by considering and compensating for the three most likely causes of error which were deemed as: error due to model or tunnel asymmetry; error caused by the wind forces acting on the connection shaft between the models and the tunnel balance, thirdly any random or human errors. The method of testing involved connecting, in turn, the reference Brick model, then the Lifting Wing, each rigidly fixed to a steel connection shaft which is fitted through the floor of the working section of the tunnel and connected to the balance (as shown above in Figures 4-12 and 4-13 above).

Once true zero (head to wind) position was established by undertaking a yaw sweep for each model, a run of tests were undertaken for each model in turn. The reference areas of the models, the wind speed, barometric pressure, air temperature, drag, lift, side-force, pitching moment, yawing moment and rolling moments, plus their coefficients, were recorded by the tunnel computer data logger (Figure 4-15 is a live screen shot of the Aerotech Balance OGI in test) at a range of wind speeds from zero to 40m/s. Each model was then rotated (yawed) on the balance through two degrees away from true zero and all measurements recorded. This was repeated by further two degree increments up to +/-20 degrees, then 1 degree increments up to a maximum of +/-25 degrees yaw. Tests for each model were re-run after powering down the wind tunnel (effectively re-
setting, or zeroing the tunnel and its data logger) to determine the repeatability of results. All results taken were within 5% of the initial result with no outliers, allowing the arithmetic mean to be utilised for the final results. Measurements for the Wing were compared to the comparable results for the reference Brick model, ultimately demonstrating the aerodynamic improvement of the Wing.

**Wind Tunnel Test Methodology**

The test was conducted in four stages:

Firstly the steel connection shaft was mounted to the tunnel balance and the wind tunnel was run at 5m/s increments from zero up to 45m/s to determine forces due to shaft alone and allow balance results for each model to be adjusted for shaft effects. To refine these results, a replica support shaft of the same diameter as the one used to support each model was raised into the tunnel to a height of 450mm. Each model was then attached to the tunnel roof via the original support shaft and lowered until it was just clear of the replica shaft fixed to the balance. This gave a more accurate balance reading of the shaft value to be subtracted from each model final measurements.

Secondly, the Brick model was mounted on the steel shaft fixed to balance. The maximum velocity (Vmax) was established by running wind tunnel from 0 m/s at 5 m/s incremental speeds, whilst ensuring drag, lift, side-force, pitch, yaw and roll loads did not exceed 90% of the limit of the wind tunnel balance. This was repeated for the Wing model, resulting in a Vmax of 40m/s, with generated forces at just over 85% of the balance limit for the Brick model.

Thirdly, a Reynolds Number (Re) sweep for the Brick at zero degrees yaw was undertaken, over incremental wind speeds from 0 to 40m/s. This allowed the calculation of the Re for the range of wind speeds, plotted to determine the minimum wind speed at which the Re becomes a constant (thus replicating full scale results). This was repeated for the Lifting Wing. Resulting Re values are shown below in Figures 4-14 a&b. These demonstrated that above Re of 600000, there is relatively little Re effect and results are as close to full scale as possible.

![Figure 4-14a. Brick Re V's Cd.](image-url)
Finally, a series of tests for both the Brick and Wing models were run, recording all required forces. The results of which are shown graphically in Figure 4-16 a&b below:

- Brick Yaw Angle Vs CDrag for 30m/s and 40m/s;
- Brick Yaw Angle Vs CLift for 30m/s and 40m/s;
- Brick Yaw Angle Vs CSideforce for 30m/s and 40m/s;
- Brick Yaw Angle Vs CPitch for 30m/s and 40m/s;

- Wing Yaw Angle Vs CDrag for 30m/s and 40m/s;
- Wing Yaw Angle Vs CLift for 30m/s and 40m/s;
- Wing Yaw Angle Vs CSideforce for 30m/s and 40m/s;
- Wing Yaw Angle Vs CPitch for 30m/s and 40m/s.

The results were recorded via the Aerotech Balance OGI, which allowed live recording of all the required forces during the testing. A live screen shot of recorded coefficients is shown in Figure 4-15.
Figure 4-15. LU Wind Tunnel Aerotech Balance OGI. Recording Lift, Pitch, Drag, Side, Yaw, Roll & Wind Speed (at 30m/s)

Wind Tunnel Test Results

An overlay of the two crucial sets of results for the Wing and Brick Yaw Angles versus CDrag at 30m/s and 40m/s, and the Wing and Brick Yaw Angles versus CLift at 30m/s and 40m/s were graphically plotted, shown in Figures 4-16a and 4-16b.

Figure 4-16a Wing and Brick Yaw Angles Vs CDrag for 30m/s and 40m/s.

The primary conclusions drawn from the CDrag overlay of the Wing and Brick were:
• The Wing profile had a dramatically lower overall drag profile (in excess of 50% less CDrag than that of the Brick), hence significantly less drag load would be induced on the cable and the crane, in all wind conditions;

• The Brick results plotted graphically exhibited a deep V, which shows a relatively large sensitivity to wind direction changes, which dramatically increase drag and swing induced loading, hence load on the crane. This feature was cross checked by undertaking flow visualisation on the Brick demonstrating a substantially increased size of the wake area and reverse flow behind the Brick, meaning increased drag;

• By comparison, the Wing plotted results exhibited a smooth, shallow curve, showing relative insensitivity to changes in wind direction, with less drag and swing induced forces, hence a more stable flight. The flow visualisation on the Wing showed smooth attachment lines running to the sharp trailing edge of the Wing, limiting the separated flow, or wake area behind the Wing, hence low drag;

• The tendency for drag to increase as yaw angle increases dropped off earlier with the Wing, reaching a maximum at around +/- 12 degrees (See Figure 4-16a) due to the sharp trailing edge and smooth flanks, whereas the Brick drag forces continued to increase as yaw angle increases to a maximum at around +/- 18 degrees as the wake area behind the Brick and reverse flow continued to grow. This demonstrated the improved stability generated by the Wing, reducing drag imposed loads on the crane in higher wind speed and with changeable wind directions.

![Graph of Wing and Brick Yaw Angles Vs CLift for 30m/s and 40m/s.](image)

Figure 4-16b. Wing and Brick Yaw Angles Vs CLift for 30m/s and 40m/s.

The primary conclusions drawn from the CLift overlay of the Wing (with Brick load inside the Wing) and Brick were:
Lift forces generated on both models were less than a $10^{th}$ of magnitude of drag forces and therefore its influence is likely to be less significant;

The Wing profile had a lower overall lift profile (less than $1/4^{th}$ of the lift of the Brick at higher yaw angles) hence significantly less rise-and-fall load would be induced on the cable and crane in higher wind conditions. This feature was checked by comparing flow visualisation on the leeward side of the Brick and the Wing. The Brick showed a more pronounced flow along the top and bottom edges, which became more dominant at the higher yaw angle. In contrast the leeward side of the Wing showed more fractured, multiple flow separation lines running from the nose toward the tail that drop away much earlier. These markedly differing flow features would explain the differing lift forces generated on each model;

The Brick exhibited a sharp and deep W profile, which signifies sensitivity of this shape to increasing wind yaw angle, dramatically increasing lift and fall induced loading, hence load on the crane. This would result in a rotation of the load when freely suspended from a crane, causing safety issues when trying to fly and land the load safely;

The Brick also showed increasing sensitivity to higher wind speed as the results for 30 and 40m/s diverge at higher yaw angles producing unstable flight characteristics as these factors increase;

By contrast, the Wing exhibited a smooth, shallow curve, showing relative insensitivity to changes in wind yaw angle or wind speed, hence less rise-and-fall induced forces and more stable flight characteristics.

Wind Tunnel Test Conclusion

Each of the tests described above were run twice and results analysed to show a high level of repeatability of generated quantitative data for both model’s drag and lift forces at varying degrees of yaw and wind speeds. The arithmetic mean was then taken to give the central tendency as there were no outlier results taken (all values were within 5% of the initial the result). Side force and pitching moment were also measured in this method, but ultimately deemed less critical, being relatively similar for both models, with slightly less pitching moment generated by the Wing under extreme yaw angles and slightly higher side forces generated by the Wing at higher yaw angles, creating a restoring yawing moment (a desirable self-correcting characteristic), ultimately producing a stable flight in changing wind direction.

These results demonstrated a significant improvement in aerodynamic characteristics of the Wing, which would at full scale provide significant reductions in critical forces generated by wind acting on the Wing, hence a reduction in forces imposed on the tower crane. These results pointed toward the Wing significantly assisting the Tower Crane Operator in their control of the tower crane in higher wind speed conditions experienced on a construction site, thereby delaying his decision to take the crane out of service at a wind speed significantly lower that the manufacturers prescribed ‘out of service’ speed.
These conclusions were further tested by conducting flow visualisation analysis of the Wing and Brick at varying wind speeds and yaw angles in the wind tunnel, discussed in the following section.

**Flow Visualisation Analysis**

A series of flow visualisation photographs of the Brick and Wing models were taken at key stages in the wind tunnel testing for each model to allow comparison of aerodynamic flow around the models. These were achieved by coating the matt-black painted Brick and Wing models with a mixture of titanium dioxide, paraffin and linseed oil. This white mixture responded to the surface shear stress of the air molecules and forms resultant flow patterns at true zero degrees, plus and minus 10 degrees and plus and minus 25 degrees yaw at varying wind speeds.

The details of this section of work is recorded in the 3rd resultant paper of the EngD ‘Lifting Wing In Constructing Tall Buildings – Aerodynamic Testing’ enclosed in Appendix C. Two example photographs of the flow visualisation of the Brick model in Figure 4-17 and the Wing model in Figure 4-18 are shown below indicating the differing flow patterns achieved by each model at the same yaw angle (-25 degrees) and wind speed (40m/s) resulting in differing drag and lift forces generated, as discussed earlier. Detailed analysis of the flow visualisation is included in Paper 3, Appendix C.

![Figure 4-17. Brick nose at -25 degrees, 40m/s.](image)

![Figure 4-18. Wing tail at -25 degrees, 40m/s.](image)

**Conclusion of Flow Visualisation**

The flow visualisation testing showed a relatively clean, stable flow over the Wing at varying degrees of yaw, demonstrating stable and predictable aerodynamic behaviour. The significantly reduced drag of the Wing compared to the Brick, along with the Wing’s invariance of drag at higher yaw angle were the key factors in proving the ability of the Wing to operate safely in higher and gustier wind conditions than a standard construction load. These observations correlated with the quantitative data taken during wind tunnel testing and reinforced the characteristics of stable and improved aerodynamic behaviour of the Wing over the Brick. These results were further tested by conducting a dynamic test of the Wing suspended in the wind tunnel.
Preliminary Dynamic Test

The objective of this dynamic test was to conduct visual analysis of the Wing’s aerodynamic characteristics under conditions reflecting, as closely as possible, suspension of the Wing from a tower crane cable in wind conditions likely to be experienced on a tall building site. No quantitative measurements could be taken during this test, purely a visual analysis of the Wing’s aerodynamic performance. This test was run three times and the results recorded on video from the side window and roof window of the tunnel working section.

It was noted during this test that minor error in model symmetry and the inability to finitely level the model effected the results and would need further refinement to achieve an accurate replication of full scale results.

The Wing model was freely suspended by three, 2mm diameter multi-strand steel cables, each with a 10kg breaking strain. These were mechanically fixed to the top edge of the model, one directly above the centre of the nose and two equally positioned on the top edge either side of the Wing, behind the widest section of the Wing. The centre line of the three wires being over the centre of gravity of the model. These wires were sufficiently long to allow the Wing to be suspended in the centre of the tunnel working section, with the wires running through a hole in the roof of the tunnel and mechanically fixed externally to support the dead and live loads of the model during testing (Figure 4-19a). This suspension method replicated the envisaged method of suspension of the full scale Wing from a tower crane.

A series of videos were taken to record the behaviour of the Wing under increasing wind speeds from 0-12m/s. These tests were then repeated with loads added inside the Wing (1kg metal plates fixed inside the wing profile) to replicate 1, 2 and 3 tonne loads on a full scale Wing (Figure 4-19b). Observations were made on Wing stability and flight behaviour from the side and roof windows of the tunnel working section.
Dynamic Test Observations

The test was initially run with no internal load and videoed from the side window of the tunnel. The Wing remained relatively static as the wind speed was increased from 0m/s to 9m/s, swinging slowly back by approximately 5 degrees from the vertical as wind speed increased to 9m/s. At 10m/s the nose of the Wing was observed to begin to move horizontally from left to right, stop and then return from right to left through the head-to-wind at zero degrees yaw. This repeating oscillation increased in yaw angle as the wind speed was increased to a maximum of 12m/s, whereupon the nose of the model, viewed from above, moved left to right whilst swinging forward and back, describing a repeating infinity (\(\infty\)) symbol movement over a distance approximately equal to half the length of the model (300mm). This oscillation reduced as the wind speed was reduced to 9m/s, whereupon the model became relatively static again, holding the 5 degree inclined position.

This test was repeated with a load of 2kg fixed inside the Wing. It repeated the pattern of the first test, with the exception that the oscillation began at the increased wind speed of 11m/s and diminished as the wind speed was reduced below 11m/s.

Finally a load of 3kg was fixed inside the Wing, again repeating the pattern of the first and second tests, with the exception that the oscillation began at an increased wind speed of 12m/s and diminished when wind speed was reduced below 12m/s.
The initial movement of the nose from left to right was deemed to be caused by a lack of absolute symmetry of the model and it being slightly out of level horizontally due to unequal lengths of its three suspension cables. These small errors created a gradually increasing turning moment on the model as the wind speed increases. However, this also demonstrates the Wing’s self-correcting characteristic, producing stability of flight at full scale, as this would ensure a slowly correcting nose-to-wind position of the Wing, desirable in changeable, gusty wind conditions typified on congested city-centre tall building sites.

Implications of Results on Wing Design

This preliminary dynamic test demonstrated that the full scale Lifting Wing would need to be made symmetrically, ideally utilising vacuumed formed thermoplastic technology or moulded carbon-fibre-reinforced polymer, plastic or thermoplastic giving the added benefits of a higher strength to weight ratio and greater ability to withstand impact deformation. Residual error could be corrected by adding a top mounted vertical stabilising fin, fixed above the trailing edge of the Wing. The dynamic test also demonstrated the need for finite adjustment of suspension cables to ensure truly level flight. Following this EngD, the dynamic test will be further refined by the introduction of turnbuckles on each of the three suspension wires above the tunnel, allowing finite adjustment of each cable length, and hence achieving true horizontal suspension of the model in the tunnel.

This test also demonstrated the proportional relationship of increasing load to more stable flight – the greater the load carried inside the Wing, the less effect the non-symmetrical features of the model had on the stability of the flight in increased wind speed. It also proved that the ultimate wind speed in which stable flight could be achieved would be directly related to the size of the load carried inside the Wing.

Overall Conclusion

The wind tunnel test quantitative data correlated with the flow visualisation and preliminary dynamic test observations. These reinforced the primary Wing characteristics of reduced drag in excess of 50% lower than the Brick and of side forces on the Wing creating a restoring moment when flying in changeable wind direction conditions, giving a desirable nose-to-wind behaviour These key characteristics at full scale should combine to reduce induced loads on the tower crane and produce stable improved aerodynamic behaviour of the Wing when compared to typical construction loads.

This conclusion demonstrates that the full scale Wing should achieve its primary purpose of increasing the ability to lift construction materials safely in higher, or more gusty wind speed conditions than is currently possible safely. Therefore the Lifting Wing design, if used on a tower crane of a tall building, should create a valuable contribution in mitigating the effect of wind causing critical path delay during the construction of a tall building, potentially reaping substantial time and cost savings. This knowledge and benefit could be transferable internationally as, without exception, tall buildings across the world are built using tower cranes which are
negatively affected by wind during the build period, delaying completion, frustrating builders from completing on time and budget and ultimately, owners from occupying their new tall buildings. These positive results will be further demonstrated by future studies utilising a full scale Lifting Wing on a tower crane, discussed in Chapter 5.

4.7 SUMMARY

This Chapter described, in chronological order, the original research work completed to fulfil the aims and objectives of the EngD, as clarified in Chapter 2 and in accordance with the research methodology, clarified in Chapter 3.

Firstly, the taught element of the EngD was presented. This element was successfully completed and officially recognised by Loughborough University awarding a Post Graduate Certificate with Distinction in Engineering Innovation and Management in December 2008.

Secondly, the Literature Review of tall building construction was described and the UK tall building market was profiled. The investigation into the future of tall buildings and the resulting working list of areas for latter stage EngD research was described. This concluded Objective 1 of the EngD – ‘Undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors’.

Thirdly, the design and development of the questionnaire tool designed to capture key information on the international tall building process from targeted leading international tall building specialists was described. The analyses of the resulting information and distillation to the key ‘wins’ & ‘losses’ on international tall building projects was presented, highlighting recurring weaknesses in the approach to high rise construction and areas for improvement. This concluded Objective 2 of the EngD – ‘to capture and analyse international survey information from Tall Building experts to determine key ‘wins’ & ‘losses’ on tall building projects’.

Finally, the rationale behind the selection of one of the most common and critical construction ‘loss’ as the focus for development of the innovative construction solution was described. The critiquing of the idea against established theory, then modelling and wind tunnel testing was presented. The results of this research were discussed and are presented in Chapter 5, Findings & Implication, validating the innovation. This concluded Objective 3 of the EngD. – ‘to develop an innovative solution to one of the most critical and common key Tall Building Project ‘loss’.
Each activity was described in detail and the relevance to the EngD research was clarified. Reference to the published papers (Appendix A-C) were made where relevant.
5 FINDINGS & IMPLICATIONS

This chapter presents the main findings and discusses the implications of the research on the sponsor company, the wider tall building industry and its contributions to existing theory and practice. It also provides a critical evaluation of the research and suggests areas for further study.

5.1 THE KEY FINDINGS OF THE RESEARCH

The key findings of the EngD research and the conclusions drawn at each stage of research work are presented below. The fulfilment of each objective by the research findings is also clarified.

5.1.1 STAGE 1

BACKGROUND THEORY - Literature Review and Market Report

The Background Theory work was conducted as an extensive literature review of tall building academic research and of the UK tall building market providing the foundation for the EngD and allowing the refinement of the objectives and selection of methods to be adopted. The seventeen main findings of this stage of the research are described in full in the Tall Building Market Sector Report, Appendix D. These findings were distilled down to the following nine key findings:

- The tall building form is not a passing design trend in the UK, it is here to stay and is currently backed from the upper echelons of Central Government down to popular public opinion;
- The UK tall building is defined in this research as twenty storeys plus, due primarily to the change in building methodology required. However, this only equates to mid-rise on the international tall building stage;
- Several new tall building clusters were being encouraged in London by Central Government, the existing London Plan, CABE and by unsatisfied demand from the office, mixed use and residential sectors;
- The three biggest threats to the continued growth of the UK tall building market were the current US-led global economic slump, UNESCO’s pressure to stop tall buildings being constructed close to heritage sites of London (particularly near the Tower of London) and the London Mayor, Boris Johnson’s threatened reverse of the current pro-tall building stance (having expressed his personal disapproval of tall buildings that block historic views);
- There are four types of UK tall buildings, driven by four distinct areas of demand, creating four sub sectors of the market: the ‘fat’ office tower (18% of market demand); the ‘thin’ or ‘iconic’ office tower (36%); the mixed use tower (18%) and the residential tower (28%);
- In the fourth quarter of 2007, London had thirty nine tall buildings potentially reaching site in three to five years, the South East had eight and the balance of the UK had thirty. The total estimated net trade cost of which is £9.77 billion, directly equivalent to the construction budget for the 2012 Olympics;
- The average gestation and build period for a UK tall building is eight years, made up of an average of five years preconstruction and three years build period;
The average view of the many independent economic forecasts considered in this research prior to 2008 for the years 2008 to 2012, was one of sustained growth for both the commercial and residential drivers of the tall building market, with an increasing focus on mixed use towers as the most efficient and sustainable tall building format. This positive economic outlook has subsequently been tempered throughout 2008 by the US led economic slump, reducing the UK’s commercial and residential markets growth potential;

The UK tall building boom overlaid with 2006-2007 financial market buoyancy and the current economic uncertainty are a mirror of the model conditions presented in the Skyscraper Index, a tool used to forecast the economic downside of building tall. This infamous index historically demonstrates that tall building construction follows the peak of a country’s economic cycle and is followed by a significant economic slump. This overlay is presented in Paper 1, ‘Britain’s tall building boom now bust?’, Appendix A and predicted an economic slump during 2008 (which was subsequently realised).

This work satisfied Objective 1, to ‘undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors’.

FOCAL THEORY - Key Tall Building ‘Wins’ and ‘Losses’

This initial literature review resulted in a focus on several key areas of research during the Focal Theory stage of the research. This was undertaken in two steps:

Firstly, data gained during the literature review was investigated in more detail for the nine key areas determined as of critical importance to the UK Tall Building industry and formed the basis for the first paper ‘Britain’s Tall Building Boom – Now Bust?’ published by the Institute of Civil Engineers for their Structures and Building Journal in June 2009 (Appendix A).

Secondly, focus group and survey research methods were utilised to identify key strengths and challenges in tall building construction. This provided the material for the second paper ‘The State of the Art of Building Tall’, published and presented at the 5th International Structural Engineering & Construction (ISEC) Conference at the University of Nevada, Las Vegas in September 2009 (Appendix B).

This work determined that one of the two most common, critical losses on tall building projects was the detrimental effect of wind on the construction process of a tall building (the other being skill levels and tall building experience of the project staff). This was distilled from the following three key findings:

- ‘Inclement weather (winding-off tower cranes)’, consistently ranked one of the two highest construction risks, followed by ‘logistical problems (man and material access via hoist and crane)’, ‘superstructure cycle times / speed of erection’ and ‘façade installation’, all of which are directly related to wind and its effect on the tower crane;
• Tall building experts believed ‘construction programme surety’ and ‘cost certainty’ were the two most significant risks to a tall build. The most important attribute of principal contractor was found to be ‘innovative build approach and the provision of an experienced tall building team’, followed by ‘history of programme certainty’, ‘logistics management efficiency’, reinforcing the industry’s thirst for innovation, desire for logistical, programme and therefore cost certainty. All of these findings are directly tackled by the new contribution stage of this research undertaken on the Lifting Wing concept;

• Of all tall building experts interviewed, 80% confirmed they would strongly embrace and promote the use of an innovative construction technique that reduces the effect of wind on tower crane material lifts on their tall building project. This finding supported the development of the Lifting Wing innovation;

The conclusion of this stage of the research was that there was strong international demand for an innovative solution to critical construction problems, the most highly ranked of which was wind negatively affecting the build. Paired with the highest ranked desire of programme certainly and hence cost certainty, this signposted that an innovative concept was needed to mitigate delays to the tall building programme duration by reducing the effect of wind on the critical path activities of the tower crane. This finding led directly to the development of the innovation of the Lifting Wing. The results gained from the questionnaire responses were analysed and formed the basis for the second published paper ‘The State of the Art of Building Tall’ (Appendix B).

The work undertaken to this point satisfied Objective 2, to ‘capture and analyse international survey information from tall building experts to determine key ‘wins’ & ‘losses’ on tall building projects’.

5.1.2 STAGE 2

DATA THEORY - Focus on a solution to one common and critical ‘loss’ with theoretical research

This stage of research involved isolating the construction ‘losses’ reported in the above work, analysing the underlying / root causes and determined the most important loss upon which to concentrate future research efforts. The key finding was:

• Wind and its critical impact on construction risk, the ability to deliver surety in programme and therefore cost of a tall building was the clearly recurring theme of the questionnaire responses returned by the international respondents.

This finding lead to a focus on ways to mitigate the effect of wind on the most critical construction instrument of the tall building, the tower crane. During this stage of the research two ideas were conceived, aimed at increasing the safety and speed of construction of tall buildings. The first was named the ‘Mag Spanner’ and the second, the ‘Lifting Wing’. They were both aimed at satisfying the diametrically opposed needs of time, cost and safety on tall building projects. The Mag Spanner was quickly developed and has been introduced on many BLL steel frame projects. It is described in more detail in the Business Plan,
Appendix E. The Lifting Wing was deemed the more important of the two innovations, with the most profound potential benefit and therefore became the focus for the final stage of research.

NEW CONTRIBUTION - Test and Prove the Innovation

This involved the development of the innovative construction technique to overcome the root cause of a key construction ‘loss’. Of the two innovative ideas, the concept with the biggest potential impact on speed of construction of tall buildings was determined as the Lifting Wing due to its potential to reduce the tall building industry accepted norm of 40% down-time for a tower crane, thereby saving time on the critical path of the tall building construction programme and hence, substantial costs. Experimental methodology was employed to test the concept. This involved firstly, theoretical aerodynamic development, followed by scale model building and finally obtaining quantitative data from wind tunnel testing and qualitative data from flow visualisation and dynamic testing. The experimental analysis resulted in the following key findings:

- The wind tunnel testing quantitative data correlated closely with the qualitative flow visualisation test findings and preliminary dynamic test observations. All three findings overlaid confirmed the primary intended Wing characteristics of reduced drag in excess of 50% lower than the reference Brick along with a desirable restoring nose-to-wind characteristic.
- These key aerodynamic characteristics combined to reduce induced loads on the tower crane and produce stable and improved aerodynamic behaviour of the Wing when compared to typical construction loads.
- The above findings demonstrated that the Wing achieves its primary purpose of increasing the ability to lift construction materials safely in higher and more gusty wind-speed conditions than is currently achievable.

The detailed findings from this aerodynamic research formed the basis for the final published paper which was accepted by Structures and Engineering Editorial Panel for the final publication in 'Buildings', in fulfilment of the EngD formal requirements (Appendix C).

This work satisfied Objective 3, to ‘develop an innovative solution to one of the most critical and common key Tall Building Project ‘loss’.”

5.2 CONTRIBUTION TO EXISTING THEORY AND PRACTICE

This research makes the following contributions to existing theory and practice in the field of innovation in tall building construction:

- Providing a unique insight into the tall building market, its value and forecast growth. Determining there are four distinct types of London tall buildings driven by four distinct areas of demand: the fat office tower (18% of market demand); the skinny/iconic office tower (36%); the mixed use tower (18%) and the residential tower (28%). The sum of these four markets meant that the demand for tall buildings
was unprecedented – ten London tall buildings were due to start on site in 2007, directly comparable in size to the Manhattan skyscraper boom of the 1920's. London had thirty nine tall buildings potentially reaching site in the next three to five years, the South East had four and the balance of the UK had fifteen. The total estimated net trade cost of which was £9.957 billion.

- Determination of a proposed definition of a UK tall building. Above twenty stories in the UK a building becomes technically distinct in its structure, services, vertical circulation, life safety and cost. This is why they deserve a different classification – the UK tall building, which is directly comparable to the classification of a global mid-rise building. It also determined that the mean gestation and build period of a UK tall building is circa eight years.

- Providing an overlay of skyscraper Index criteria on 2007 market conditions and the forecast of a global financial crisis.

- The development and implementation of a method to collect data from a wide spread of specialists within the tall building sector of the construction industry. This captured the five key areas of the global tall building industry across geographical and disciplinary spread, providing a snap shot of the state of the art of the international tall building industry, the key risks of the tall building build process, desired principal contractor key features, analysis of new techniques from overseas and other industries and determination of the key tall building ‘Wins’ and ‘Losses’.

- The development of two innovative concepts in response to the two most important issues identified as challenges in tall building construction: improving the health, safety and productivity of the tall building construction site; the Mag Spanner and the Lifting Wing. The Wing will be further developed through future research following the EngD completion.

- The development and implementation of a scientific method to test the aerodynamic improvement of a model of the Wing over the typical construction crane load.

- Contribution to partially redress the imbalance due to the vast majority of existing tall building research being focused on the structural, services and architectural design. This research contributes to the body of knowledge on the actual construction of tall buildings.

### 5.3 IMPLICATIONS/IMPACT ON THE SPONSOR

The EngD research process and outputs helped raise awareness and noticeably raised interest levels in tall buildings within BLL. This was reflected in the significant increase in membership levels of the BLL High Rise Community of Practice, an internal specialist interest group set up to focus on the tall building market sector, chaired by the RE. Membership increased from 11 in 2007 to 32 by 2010. The EngD also assisted in raising BLL’s professional profile externally in the London (and to a lesser extent the international) tall building market sector and help reinforce BLL’s perceived level of appetite to build these relatively high-risk construction projects. This was mainly achieved through the RE speaking at several tall building conferences and also through networking at these specialist conferences and by contacts made during the research period. The EngD also
assisted in raising BLL’s profile within Academic circles as an innovator, supporter of the CICE, the EngD programme and of higher education generally in the discipline of construction, tall buildings and innovation.

As a result BLL has benefited from:

- A unique insight into the tall building construction market through the Market Analysis which calculated the market value at nearly £10 billion (Net Trade Cost) and forecasted its growth prospects;

- An investigation into the future of tall buildings which set out a wide range of potential areas for further study during the remaining research period of the EngD. This enabled BLL’s EMT to influence the direction of the final stages of research on what was deemed to be the most valuable of the research options for the corporation;

- Higher corporate visibility in the tall building industry, predominantly in London, then UAE and America (where the RE presented), but also gave wider international visibility via engagement with the respondents of the questionnaire by the RE at numerous international specialist conferences;

- An increase in interest levels of BLL staff in the tall building specialist market sector, demonstrated by the increase in membership to the BLL High Rise Community of Practice;

- The first invitation to tender for a tall building since 2006. This was received directly from the Client, W.R. Berkley Corporation, for the Lime Street Tower also known as the ‘Scalpel’, a bespoke tall building to be constructed in the City of London, adjacent to the ‘Gherkin’ and opposite to Lloyds of London. This lead came from two sources within BLL, one of which was via a contact made by the RE during the EngD research;

- A unique solution to mitigate a key tall building ‘loss’, providing a USP in the tall building construction market.

The sponsor company was therefore in a unique position at the end of the EngD to maximise on the unique position established in the London tall building market, but also on the international market.

**5.4 IMPLICATIONS/IMPACT ON WIDER INDUSTRY**

The Chartered Institute of Building published their Report Number 24 in June 2008 which found that two-thirds of high-rise projects are finished late. Their research shows a high proportion of complex schemes are delayed. The worst offending were high-rise construction projects, with two-thirds being completed late and almost a fifth more than six months behind schedule. This reinforced the recognition of the need in the wider industry for methods of mitigating delays to programme, especially for tall building projects.

The literature review highlighted substantial gaps in existing research undertaken in the actual build process of tall buildings. The vast majority of existing tall building research had been undertaken in structural and architectural design. This EngD work partially redresses that imbalance. The RE and co-authors of the papers produced during the EngD believe this research has produced an important innovation that can potentially provide substantial benefits to the tall building industry. Following the completion of the EngD and thesis
publication, funds are planned to be made available to build and test a full scale Wing, prior to taking the proposition to market.

Additionally, falls on site of either materials or man are acknowledged across the industry as the biggest safety hazard on a site. This area was researched in more detail as part of this study and culminated in the innovation named the ‘Mag Spanner’. In trials on a BLL steel frame site, the spanners were well received by the steel frame contractor and operatives. Their use during the trial significantly reduced the number of items dropped from height over the period tested. It has since been adopted on several UK BLL sites with a steel structural frame. This could have the potential to reduce accidents on site if adopted across the industry.

5.5 RECOMMENDATIONS FOR INDUSTRY/FURTHER RESEARCH

Having considered the findings of the research undertaken for this EngD, a number of recommendations for further research can be made.

Firstly, this research uncovered a number of key wins and losses of tall building projects, many of which were not selected for the final focus of this research. Several of these are considered to have potential far-reaching implications on the building of tall buildings. Further research into the root causes of these wins and losses would be beneficial to the industry. The two of the most significant are:

- The industry’s leading practitioners believe that the construction industry is not keeping pace with cutting edge designs for tall buildings and from a UK perspective, it highlighted that the UK was deemed not to be keeping up with overseas construction industry developments and was ranked as joint sixth out of seven countries for an innovative approach to construction. This shows the industry as a whole and particularly the UK, needs to increase the level of innovation in the tall building construction process. Barriers to innovation in the UK construction industry, particularly with respect to tall building projects should be researched further, alongside methods to increase motivation to innovate.

- The risk that was rated the highest in the tall building process across all geographical and disciplinary sectors was the provision of experienced principal contractor staff, showing the majority of the industry feel they are under-resourced with skilled and experienced tall building professionals. This theme was also reflected by the top rated principal contractor attribute being ‘provision of an experienced tall building team’. Additionally, the most common tall building ‘win’ was related to a high quality construction and management team, and most common ‘loss’ was related to a poor quality construction and management team, lacking tall building experience and skills. The recurring theme of the responses throughout each section of the questionnaire point to an excess demand for tall builders and insufficient supply of skilled resources to satisfy. Further research could investigate methods of increasing the level of specialism to satisfy this demand and investigate ways to ensure this skill set can be transferred to other types of complex major projects during the relatively cyclical tall building market downturns.
Secondly, further research into the aerodynamic performance of the Lifting Wing and design refinement work is warranted, including:

- A further refined dynamic test of the scale model Lifting Wing will be undertaken by the RE on completion of the EngD, allowing the model to be hung perfectly level in the wind tunnel. This is planned to be achieved by the introduction of turnbuckles on each of the 3 suspension wires above the tunnel which would allow finite adjustment of each cable length, hence achieving a true horizontal suspension of the model in the tunnel. Additionally, the model would be further refined to ensure it is as near to symmetrical as possible. The fitment of an adjustable tail fin would also be considered to ensure the model sits at true nose to wind (zero degree yaw angle) when in circa 10m/s wind speed, thereby preventing the previously experienced repeat oscillation which increased in yaw angle as the wind speed increased. This would provide further refined aerodynamic results, better reflecting the increased efficiencies gained by the lifting wing.

- This would be followed by the next stage of the Wing development to be undertaken by the RE post EngD, which is to construct a full scale model and dynamically test it utilising a Saddle Jib or Luffing Jib Tower Crane on a sponsor company site. In this test, an experienced Tower Crane Operator will lift a rectangular ‘brick’ shaped reference load in wind conditions approaching industry-recognised winding off speeds. The load will then be placed inside the full scale Wing and lifted in the same wind conditions. The Operator will be asked to note flight characteristics of each lift and determine the increased wind speed in which the Wing can still be lifted safely. This quantitative analysis will rely on the feedback from the Operator, rather than any measured force data. However, it is exactly this Operator analysis that is used across the industry to determine the safe limit of lifting by cranes on every site the world over. If Tower Crane Operators feel the Wing allows extended lifting in higher wind conditions, then it will have succeeded.

An international patent has been applied for covering the Lifting Wing and research undertaken to date.

5.6 CRITICAL EVALUATION OF THE RESEARCH

At inception, the aim of this EngD was closely aligned with Bovis Lend Lease organisational strategy and planned as a USP or key differentiator in winning tall building work. Its outputs were planned to be a valuable resource in developing best practice solutions to meeting future tall building challenges in the UK. This was unfortunately superseded by the global recession from 2007 until early 2013, when demand for tall buildings reduced significantly or stopped completely in many countries. The only tall buildings to be constructed during this period were those that had already started and were committed to financially. During this period the EngD was threatened with termination as it was seen as a redundant work area by the sponsor company. This stalled the research for a significant period as the RE was redirected to bid, win and deliver projects. Fortunately, this started to change during mid-2013 as tall building projects began once more to make financial sense and the sponsor company became keen to pursue tall building projects,
although in a more risk adverse position than before the global financial crisis. This caused prolongation of and a disjoint in the research as the first 2 years were conducted in the peak of the market and the last 3 during the tale-end of a global recession and a cautious economic growth period, resulting in some disparity in the research results. Fortunately, in the closing stages of the EngD the original aim is now re-aligning with post-GFC corporate strategy and become meaningful once more. The first paper can now be considered out of date and therefore warrants refreshing to reflect the current market status, forecast growth and overlay the current market conditions on the Skyscraper Index criteria to determine if the next recession is indeed imminent.

To this end, the questionnaire results determined from the focus group, pilot study and semi-structured questionnaire interviews during 2007 and 2008 tall building conferences may reveal differing results if this was repeated in today’s market conditions. This may also reveal new tall building ‘wins’ and ‘losses’. The findings determined in this research may therefore be considered to be worthy of refreshing.

The final stage of this study is limited by the need for a full scale case study to prove that the experimental findings are repeatable at full scale, as established aerodynamic theory suggests. This cannot be conducted within the period of the EngD due to both time and financial constraints. However, further testing has been described within this thesis, including the proposed full scale testing methodology. The next stage of research, post EngD, would require significant funding to undertake and act as a post-EngD case study for the Lifting Wing.

5.7 SUMMARY

This chapter presented the original findings of the research and the conclusions drawn at each stage of that research work. The fulfilment of the overall EngD aim and of each objective by the research findings were also clarified at each stage. The implications of the research on the sponsor company, on the wider tall building industry and the contributions to existing theory and practice were discussed. Critical evaluation of the research was presented and significant areas for further study were proposed.

The key findings of the research discussed earlier in Chapter 5 are summarised below, determined in three key stages driven by the three objectives of the EngD:

Objective One
‘Undertake a Literature Review and profile the UK Tall Building market for value, growth and demand sub-sectors’ - From early 2006 up to the freeze induced by the world’s faltering financial markets during the first quarter of 2008, Britain experienced demand for tall buildings of an unprecedented high level - in London alone, ten tall buildings had started, or were due to start on site between first quarter of 2007 to the fourth quarter 2008. This was directly comparable in size to America’s Manhattan Island skyscraper boom of the 1920’s. The aims achieved in this first stage of research were: firstly, the investigation the evolution of the UK tall building construction and determination of the reasons behind
its growth at previously unprecedented rates; secondly, the creation of the definition of the UK tall building of 20 storeys and up, and contrasting it to the international tall building stage; thirdly, the analysis of the differing types of demand and definition of the four resulting sub sectors of UK tall building market; finally, the calculation of the size and value of the tall building market, the forecast of its growth potential and the modelling against the ‘Skyscraper Index’, ultimately demonstrating that a financial crisis was looming;

Objective Two
‘Capture and analyse international survey information from Tall Building experts to determine key ‘wins’ & ‘losses’ on tall building projects’ - This stage of the research captured the global state-of-the-art of the tall building industry. This was achieved by: firstly, designing a questionnaire which tackled the most pressing issues of the tall building process; secondly, targeting the questionnaire at the most active tall building professionals around the globe; and thirdly, gaining an 80% response rate, giving a great insight to the differences of opinion from Dubai to London, China to Chicago, Sydney to Vietnam. The research was conducted in five key tall building areas: the current state-of-the-art of the international tall building industry; the build process of a tall building; the tall building principal contractor key features/issues; ‘wins’ and ‘losses’ inherent with past tall building projects; and new techniques from overseas and other industries that could be adapted to the construction industry. The analysed results gave some surprising conclusions, but offered a clearly signposted way ahead for innovative construction of tall buildings, headlining on ‘wind’ and ‘expertise of project staff’ as the two of the most common critical issues;

Objective Three
‘Develop an innovative solution to one of the most critical and common key tall building project losses’ – This stage of the innovative research was undertaken into one of the two most common critical issue raised by the global tall building experts in the second stage of research: that of wind and its profound negative effect on the construction critical path of the tall building. Theoretical and aerodynamic research was undertaken, culminating in model making, wind tunnel testing and analysis of the ‘Lifting Wing’. This demonstrated the Wing’s potential to allow building material to be lifted by tower cranes in higher and more unstable wind conditions, reducing the construction duration of a tall building.

This EngD research fulfilled its vision of exploring the challenges that face the builder of tall, increasingly irregular structures and determined a new solution to one of the most critical issues. This new solution, the Lifting Wing, has the potential to improve the build speed, safety and hence commercial viability and sustainability of tall buildings. In response to Col W. A. Starrett’s 1920’s analogy of the building of skyscrapers being the nearest peacetime equivalent to war, the Lifting Wing provides air support as did the flying aircraft carrier dirigible USS Macon.

To date there had been little research in this building area, in contrast to the voluminous research on the structural, architectural and sustainability design of tall buildings. This EngD partially redressed that imbalance.
Figure 5-20. USS Macon over New York City, Summer 1933. US Naval History & Heritage Command.
6 REFERENCES


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APPENDIX A  PAPER 1

Structures and Buildings

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Editorial

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This issue starts with an impressive set of full-scale loading tests. It is rare to find such large-scale testing of portal frame structures. The tests are based upon tapered portal frame structures designed using BS 5950. Although this structural type has existed for a long time, much of the testing was done over 30 years ago before the common use of finite-element (FE) modelling. The authors (Rankin et al.) propose that this form of construction will become more popular as automated welding technology becomes more widely available. Certainly, the ubiquitous nature of portal frame modelling software is no impediment to this form of construction. It is a pity that the BS 5950 code is about to be made obsolescent by the introduction of Eurocode 3.

The next paper in the issue, by Skelton et al., looks at economic trends in tall building design. It examines the cyclical nature of tall building construction, and suggests how the ‘Skyscraper Index’ can be used to predict recession; obviously a very topical subject. Although not a pure engineering paper, the subject matter should be of interest to all involved in high rise design and construction—it is the market that drives the construction of high rise.

Vielma et al. look at a common form of construction, the waffle slab, which is used frequently in Europe and Latin America. It is also used frequently as part of the seismic resistance of a building structure. The Spanish earthquake resistant design code NCSE-02 gives rules for their use and it is this application that is the subject of the paper. The performance of waffle slabs is compared against moment frames and, not surprisingly, the moment frames perform better. The authors conclude that the prescribed ductility levels stated within the code are too high and the best way to improve the performance of waffle slabs is to increase their depth!

Continuing a long string of papers examining structures and fire, Khoury et al. look at the fire safety evaluation in tunnels. In this case, the approach is holistic, looking at the social and economic consequence of fires, methods of evaluation, escape strategies and upgrading options. This is set against a background of an EU directive setting minimum safety standards.

Adam et al. provides a second paper on the subject of columns strengthened by steel cages. The same authors have previously written on the same subject. In this case the axial capacity of the strengthened columns is reviewed, comparing experimental and FE test results.

Lastly, we have some discussion on Eurocodes and a book review. The discussion relates to risk and reliability in Eurocodes, particularly with respect to the partial safety factor. A number of cases are examined, reviewing how simplifications in the factoring system can lead to some unusual scenarios. An interesting read to anybody who ever uses load factors.

REFERENCES
Britain’s tall building boom: now bust?

I. R. Skelton AE Dip, MCM/MPM, P. Demian MEng, MA, MSc, PhD, MASCE and D. Bouchlaghem Dip.Arch, PhD

From early 2005 up to the freeze induced by the world’s faltering financial markets during the first quarter of 2008, Britain experienced a demand for tall buildings of an unprecedented high level: in London alone, ten tall buildings have started, or were due to start on site, between the first quarter of 2007 to the fourth quarter of 2008. This is directly comparable in size with America’s Manhattan Island skyscraper boom of the 1920s. The objectives of this paper are: first, to investigate the evolution of the UK tall building and determine the reasons behind this building form’s growth at unprecedented rates; second, to define the UK tall building and compare it with the international tall building stage; third, to analyse the differing types of demand and categorise these subsectors of the UK tall building market; fourth, to calculate the size and value of this specialist construction market in the UK and forecast its growth potential; and finally, to analyse the latest negative market developments during 2008 and warn of the current match of the UK tall building market to the Skyscraper Index model and the resulting risk of full-blown economic recession.

1. INTRODUCTION TO RESEARCH: KEY FINDINGS

The literature review and new research for this paper include several key findings.

The tall building form is not a passing design trend in the UK, it is here to stay and is currently backed from the upper echelons of central government down to popular public opinion (see Figure 1).

The UK tall building is defined in this research as 20 storeys plus, owing primarily to the change in building methodology required. However, this only equates to mid-rise on the international tall building stage (see Figure 2).

Several new tall building clusters are being encouraged in London by central government, the existing London Plan, Commission for Architecture and the Built Environment (Cabe) and by unsatisfied demand from the office, mixed use and residential sectors.

The three biggest threats to the continued growth of the UK tall building market are the current US-led economic slump, recent pressure by the United Nations Educational, Scientific and Cultural Organisation (Unesco) to stop tall buildings being constructed close to heritage sites of London and Liverpool, and new London mayor Boris Johnson’s potential reverse of the current pro-tall building stance, having expressed his personal disapproval of tall buildings that block historic views.

There are four types of UK tall building, driven by four distinct areas of demand, creating four subsectors of the market: the ‘fat’ office tower (18% of market demand); the ‘thin’ or ‘iconic’ office tower (36%); the mixed-use tower (18%); and the residential tower (28%).

In the fourth quarter of 2007, London had 39 tall buildings potentially reaching site in the next three to five years, the South East had eight and the balance of the UK had 30. The total estimated net trade cost of which is £9.77 billion, directly equivalent to the construction budget for the 2012 Olympics.

The average gestation and build period for a UK tall building is eight years, made up of an average of five years preconstruction and three years build period.

The average view of the many independent economic forecasts considered in this research prior to 2008 for the years 2008 to 2012, was one of sustained growth for both the commercial and residential drivers of the tall building market, with an increasing focus on mixed-use towers as the most efficient and sustainable tall building format.1–8 This positive economic outlook has subsequently been tempered throughout 2008 by the US-led economic slump, now reducing the UK’s commercial and residential markets growth potential.

The UK tall building boom overlaid with 2006–2007 financial market buoyancy and the current economic uncertainty are a mirror of the model conditions presented in the Skyscraper Index,9 a tool used to forecast the economic downside of building tall. This infamous index historically demonstrates that tall building construction follows the peak of a country’s economic cycle and is followed by a significant economic slump.

2. EVOLUTION OF THE TALL BUILDING

The skylines of many world cities are defined and punctuated by tall buildings. The drivers for such dominant skylines range from land scarcity and social needs, high real estate values, commercial opportunity and corporate demand, through to...
metropolitan signposting. This obsession with the still-current form of tall, slender buildings can be traced to the Italian patrician families who created the eleventh century skyline of San Gimignano by building 70 tower-houses, some 50 m tall, as symbols of their wealth and power (see Figure 3). This was most famously followed in the late nineteenth century with the Manhattan skyline. This obsession with building tall continues to spread worldwide and is forecast in this research to grow into the future. Even after the World Trade Center towers collapsed following a terrorist attack in September, 2001, the tall building format is very much here to stay.

The development of increasingly sophisticated construction materials and technologies has driven the evolution of the modern tall building throughout the twentieth and early twenty-first century. The resulting structures have reflected this evolution in height, but the form has generally adhered to one of only two design philosophies—straight up or stepped—owing to twentieth century light-protecting planning laws (see Figure 4).

The new ‘iconic’ breed of innovatively designed tall buildings, however, brings unprecedented challenges to the developers, designers and not least, the builders: commercial feasibility must be achieved; technological obstacles must be overcome; cutting edge design must be converted into a built reality; safety of its builders and occupants must be ensured; risk of cost and programme overrun must be minimised. Tall challenges for the tall building industry to surmount.

2.1. The rise and rise of tall buildings in London

Britain’s experience of tall buildings has been blighted by post-war regeneration. The 1950s to 1970s produced a large number of local authority housing towers and brutalist office towers between ten and 30 storeys high. The high-profile failure of many of these post war experiments was attributable to weak design, detailing and construction, which led to a general rejection of the high rise form in the 1980s and a focus on the conservation and heritage building arenas. There were a few exceptions to this rule in the first generation of UK tall buildings, the most successful of which have now achieved listed building status, including Centrepoint (grade II), BT tower (grade II) and the Trellick tower (grade II*).
Over the last ten years, general interest in tall buildings has risen to new heights, both in the commercial and residential sectors. This is evident on the supply side, especially in London, where a pro tall building stance is notable in: The London Plan; the number of planning proposals submitted for tall buildings; the granting of planning consent to new proposals such as Heron tower, the Shard in Southwark, 122 Leadenhall building, 20 Fenchurch Street, DIFA (or Bishopsgate) tower and Columbus tower; the recent completion of numerous tall buildings in various London locations such as Paddington, the West End, the City (London’s financial district) and Canary Wharf; the successful refurbishment of first-generation tall buildings including Tower 42 and City Point. In response to this favourable profile, signature architects are now scrambling to design tall buildings.

This high profile is also reflected in the demand side. There is now a strong City ambition to build high. This has grown from Foster and Partners’ form-breaking design for the Swiss Re building, 30 St Mary Axe (the Gherkin), which won support from Cabe, English Heritage and the City, all of whom were keen to secure bespoke headquarters for major commercial institutions. The continuing high-profile success of 30 St Mary Axe undoubtedly led to increasing demand for more commercial towers. The Heron inquiry followed and forced the evolution of city policy, developing the concept of an ‘eastern cluster’ in the city, not affected by St Paul’s Cathedral heights, grid, strategic viewing corridors, or conservation areas. The forthcoming 50-storey 122 Leadenhall building currently being built by Bovis Lend Lease will become the focal point of this new tall building cluster.

The rising profile of London as a ‘world city’ over the past decade, allied to the refocus of the planning system for high-density developments and brown field schemes, has assisted this growth in building tall. London, commonly seen as the de facto capital of Europe, is consolidating its position as a world-leading financial centre, second only in trade value to Frankfurt. The new London mayor believes London is now challenging Tokyo and New York as their only global competitor. Planning policies laid down by the previous mayor underpinned this vision, permitting the provision of world-class office space and infrastructure and encourages ‘London to continue to reach for the skies’.

It is apparent from research undertaken for the present paper that the current suite of tall buildings being constructed in the heart of the City (122 Leadenhall, the Shard of Glass, the Gerkin, Heron tower, 20 Fenchurch Street, the DIFA or Bishopsgate tower and the Broadgate tower) were all commissioned due to the threat of London Docklands on the City’s position in the mid-1990s. The City responded by relaxing plot ratios to encourage development. The reaction to a ten year old threat is now finally hitting the streets, even though the threat is long gone as Canary Wharf has been 90% full for the last three years.

3. DEFINING A UK TALL BUILDING
The second objective of this paper is to define a UK tall building and compare it with the international tall building stage. This research has defined the UK tall building as between 20 to 80 storeys, approximately 70–300 m (depending on whether the building has commercial or residential floor to floor heights). A generally accepted definition of a tall building in town planning terms is one which stands above the prevailing skyline. A good construction definition has been determined as a building which has technical and design differentiation from its neighbours. Even with modern build methods, above 20 storeys a building becomes technically distinct in its structure, services, vertical circulation, life safety and cost. Therefore, above 20 storeys, a different classification is required: the UK tall building.

Research undertaken for this paper shows that of the 77 UK tall buildings currently proposed, almost 70% by value are in London. This report therefore focuses on London, but also considers the South East and the balance of the UK (‘other regions’).

3.1. London high rise = global mid rise
London’s skyline is predominantly low rise with distinct pockets of medium to high rise, allowing space for the St Paul’s Cathedral sightlines to strategic London viewpoints. At the top end of the London scale are the proposed London Bridge tower and the Bishopsgate tower in excess of 300 m high.
containing 80+ storeys. The lower end of the London scale is dictated by the need at this height for technological changes to the way buildings are constructed, utilising tall building techniques as opposed to low-rise construction techniques.

New York’s Manhattan Island is widely recognised as one of London’s main competitors for the status of financial centre of the world. Its skyline, by comparison with London’s, is predominantly medium rise with widespread pockets of high rise. A tall building (skyscraper) here is deemed to be 30 to 100+ stores (although local fire codes change at 15 storeys). In the last seven years America’s appetite for commercial tall buildings has cooled, but residential demand remains strong and international developments are beginning to influence corporate decision making in New York, especially regarding sustainable design. The future of the skyscraper seems assured in New York City, even after the soul-searching in Manhattan after the loss of nearly 3000 lives in the World Trade Center collapse.

Tokyo is the second main competitor to London for the status of financial centre of the world. The Asian skylines of central Tokyo, Hong Kong and Shanghai, in comparison with London’s, are predominantly high rise with isolated pockets of low rise on the peripheries. Asia is regarded as the natural environment of the very tall building, the format of which makes sense where density and the urban infrastructure make it the logical way to occupy land. High density is a historically accepted norm in much of Asia. Many towers are simultaneously going up in Hong Kong, Guangzhou, and the other high-growth Asian cities. The tallest, densest buildings are rising over rail stations, with airport access. With the massive Chinese population rapidly industrialising in a modern version of Victorian Britain, there is a boom in tall buildings on an unprecedented scale. China currently has around 60, 300 m+ buildings, or ‘supertalls’, at some level of development.

This research finds that the UK tall building is therefore defined as a building of 500 000 m² total area. This is usually a planned amalgamation of four different types, or subsectors of tall buildings.

The second tall building subsector is represented by small international companies demanding a prestige location in a multi-tenanted, ‘thin’ or ‘iconic’ building. Their floor plate requirement is 1000–2000 m² gross. They value prestige, high quality, shared facilities and opportunities for interrelations with neighbouring businesses. The demand of this type of occupier is shown by low vacancy rates and high rental yields for these iconic buildings. These types of offices are regularly achieving £100 per sq ft across London, a new record set during the fourth quarter of 2006.

A third, emerging tall building subsector is the mixed-use tower, incorporating a mix of residential, retail, office and possibly hotel and leisure space. This ‘mixed-use’ tower is rapidly growing in popularity owing to high potential returns on investment. The renaissance of residential tall buildings is attributable to increasing house prices outstripping build cost inflation along with the rising profile of ‘city living’. This has lead to a relatively new phenomenon of a price premium relative to the height of the residential development.

The fourth tall building subsector is the tall residential market, rapidly growing in popularity owing to high potential returns on investment. The tradition of tall residential buildings in the UK is relatively new and has been driven by rising house prices outstripping build cost inflation along with the rising profile of ‘city living’. This has lead to a relatively new phenomenon of a price premium relative to the height of the residential development.

Research undertaken for this paper shows the fourth quarter 2007 tall building market subsector split for London is: 54% commercial towers (18% fat and 36% iconic); 28% residential towers and 18% mixed use towers, shown graphically in Figure 5.

The sum of these four tall building subsectors shows that London’s demand for tall buildings was at an unprecedented level in December 2007. The UK construction industry now waits to see the impact of the US-led economic slump throughout 2009.

4. WHO IS DRIVING DEMAND FOR LONDON TALL BUILDINGS?

Research undertaken for this paper shows that little academic work has been done on analysing the tall building market and categorising the demand for different types of tall buildings; this forms the third objective of the current paper. Research undertaken during 2007 has determined that there are four distinct occupiers of tall buildings in London, driving demand for four different types, or subsectors of tall buildings.

The first tall building subsector is represented by large corporations wishing to relocate in a single building, requiring a ‘fat’ tower with large floor plates of 3000 m² gross and up to 50 000 m² total area. This is usually a planned amalgamation of various operations, aimed at creating synergies and savings between business units, plus reducing facilities management costs. Examples include HSBC, Citigroup, Barclays and most recently, JP Morgan, who are moving to Canary Wharf as it offered the right mix of floor plate, quality of space, size and critical mass of complementary businesses. These types of offices are now achieving an average rent of £70 per sq ft (1 sq ft = 0.09 m²) across the seven London fringes.

The second tall building subsector is represented by small international companies demanding a prestige location in a multi-tenanted, ‘thin’ or ‘iconic’ building. Their floor plate requirement is 1000–2000 m² gross. They value prestige, high quality, shared facilities and opportunities for interrelations with neighbouring businesses. The demand of this type of occupier is shown by low vacancy rates and high rental yields for these iconic buildings. These types of offices are regularly achieving £100 per sq ft across London, a new record set during the fourth quarter of 2006.

A third, emerging tall building subsector is the mixed-use tower, incorporating a mix of residential, retail, office and possibly hotel and leisure space. This ‘mixed-use’ tower is rapidly growing in popularity owing to high potential returns on investment. The renaissance of residential tall buildings is attributable to increasing house prices outstripping build cost inflation along with the rising profile of ‘city living’. This has lead to a relatively new phenomenon of a price premium relative to the height of the residential development.

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![Figure 5. London’s proposed tall buildings, the fourth quarter of 2007](image-url)
5. METHODOLOGY OF THE MARKET ANALYSIS

The market analysis undertaken for this paper created a unique snapshot of the UK tall building market in the fourth quarter of 2007. It captured the market’s mood, categorised the types of demand, determined the market’s current value and was then used to forecast its growth. The full picture of the tall building market presented in this analysis was built up from a blend of new data generated during this research, live information gained from industry-recognised expert sources by way of targeted interviews and questionnaires, plus in-house theoretical and practical construction market knowledge. The analysis concentrates on London as it forms almost 70% of the current UK tall building market by value, but also considers other areas of the UK.

5.1. Cataloguing current UK tall buildings

A catalogue of all proposed UK tall buildings was compiled to determine the size of the current tall building market in the UK, the type of tall building, the proposed height above ground, the feasibility of actually being built and also captured construction cost information, if available. This tall buildings catalogue was then filtered to include only those tall buildings deemed to be feasible of reaching site in the next three to five years and exclude ‘visionary’ tall buildings with a low likelihood of being built owing to their being out of context with their location through extreme height, outlandish design, impracticalities of proposed occupier use, or being a high-density scheme submitted for planning approval to purely increase site value. The catalogue contains 77 proposed UK tall buildings. It has been broken down geographically into ‘London’ (which has 39), the ‘south east’ (which has eight) and the ‘balance of the UK’ (which has 30) and then sorted into the previously determined four tall building subsectors: commercial (fat), commercial (iconic), mixed use and residential for each geographic area. This breakdown is shown in Figure 6.

5.2. Calculating current UK tall building market value

Definitive or reliable construction cost information can rarely be found for the majority of projects owing to the confidential nature of finance for tall buildings; therefore, the shell and core construction costs of five Bovis Lend Lease tall building projects were utilised. These tall building projects were selected on the basis of being a London project that would feasibly enter the construction phase with the next three to five years, having had the cost plan checked for robustness during 2006 or 2007, the projects consisting of competitively tendered packages under a construction management form of contract and the projects proportionately representing the four previously determined UK tall building market subsectors. The project details of the five selected tall buildings are withheld owing to the confidential nature of the project information, but can be suitably described as

(a) tower 1: a signature-architect-designed tall commercial building in the City; construction commenced in the first quarter of 2008
(b) tower 2: a signature-architect-designed tall commercial building in the City; construction commenced in the second quarter of 2006
(c) tower 3: an existing tall commercial building in the City, stripped, structurally extended and comprehensively refurbished; construction commenced in the third quarter of 2006
(d) tower 4: a signature-architect-designed tall commercial building in the City; construction due to commence in the second quarter of 2008.
(e) tower 5: a signature-architect-designed residential tower in London; construction due to commence in the third quarter of 2008.

These figures were supplemented by independently published construction cost projections for tower 6—London Bridge tower (the Shard), the UK’s tallest mixed-use building, which entered the construction phase in the first quarter of 2008.

The net trade shell and core construction cost per meter height of building above street level was then selected as the most reliable, publicly available metric common across all tall buildings in the catalogue. This metric is historically reliable and generally one of the first facts published for a tall building, which can be used to extrapolate the value of the total UK tall building market.

A range of costs were found across the six sample tall buildings, the extremes of which were tower 5, the 44-storey, slender residential tall building and tower 6, the 82-storey, mixed-use London Bridge tower. The disparity of cost between the two buildings is fundamentally attributable to height, differing design complexity, the structural solution adopted, floor plate sizes and the performance and complexity of the cladding and services specified. These realistically reflect the two book-ends of the UK tall building spectrum.

The average of the sample tall building net trade shell and core construction costs per meter height was multiplied by the cumulative height of the filtered catalogued tall buildings for each geographical location in the UK, then factored utilising published tall building cost location factors (London and the South East cost index 1, the balance of the UK an average cost index of 0.92). This results in the calculation of the total value of the UK tall building construction market.

(NTC represents net trade cost, which, in this calculation is defined as a tall building shell and core construction cost, excluding demolition and enabling works, external works, incoming services and fit out, developer’s professional and statutory fees, taxation, insurances, finance charges, disposal costs and design and construction related professional fees, VAT and any site abnormalities.)
Average construction (NTC) cost per m height = £1.03 m/m height.

Therefore, total construction value for tall buildings in London and the South East = cumulative height of catalogued tall buildings \times \text{average NTC/m height} = (6968 \text{ m London} + 422 \text{ m South East}) \times £1030000/m = £7611700000.

Using the same method of calculation, the total construction value of tall buildings in the balance of the UK (location factor 0.92) = 2277 m \times £1030000/m \times 0.92 = £2157700000.

Therefore, the total construction value for the current UK tall building market = £9770000000.

To determine the potential UK tall building construction value per year, the average gestation period of a UK tall building needs to be determined. By analysis of the 20 most recently awarded UK tall buildings for construction up until the fourth quarter of 2007, the average UK tall building gestation period (from project planning proposal date to completion of construction date) has been calculated as eight years. This consists of an average period of five years for preconstruction (from initial project planning proposal to start on site) and three years for construction (from start on site to completion of construction) (see Figure 7).

Owing in part to the current uncertain economic climate, it is not certain when any building on the tall building list will progress from planning and preconstruction into the construction phase and hence generate potential construction spend for that year, so an equal spread over the average gestation period of eight years must be assumed. This gives an average annual construction spend (construction market value) of £1221200000 for the UK tall building market from 2007 until 2014 inclusive.

6. DISCUSSION

This forecast construction value for the UK's tall building market is of a scale directly comparable with the latest government declared construction budget for the 2012 Olympics of £9-325 billion pounds over seven years (2006–2012), but is not a one off event. If this building form is nurtured, it has the potential to deliver this order of value year on year into the future.

It is recognised that the London Olympic win has increased delivery pressures on the current set of tall buildings. 2012 has become an artificial deadline for a large number of major projects, which will cause consolidation of work.22 There is concern that the simultaneous start of construction of a significant number of these tall building projects, running concurrently with the Olympics, will overheat the construction market, creating local shortages of skilled labour and materials and force prices up by factors of up to 20% for steel reinforcement and concrete. The 2007 market forecast report summarises that the top and bottom of London’s construction market is polarising, whereby large projects are suffering from greater inflationary pressures, while smaller schemes retain a more competitive edge.23

This forecast of rising construction costs has not noticeably dampened the demand for the UK tall building, possibly because its effect was swamped early in 2008 by the US’s economic uncertainty and risk of global recession, the effects of which are now starting to be seen in the UK tall building market by the stalling of some speculative developments and a requirement for higher pre-let percentages prior to construction start.

Bringing this forecast up to date with recent economic developments as of the fourth quarter of 2008, the amount of commercial development in the UK has fallen to its lowest level in five years24 and is directly attributed to tighter bank lending conditions, deteriorating market sentiment and weaker growth prospects for the global economy. This commercial fall could affect three of the four tall building markets (fat office, thin/iconic office and mixed use), the residential sector being separately affected by the current UK housing market stagnation caused by a lack of liquidity in the mortgage market.

The tall building boom presented here, overlaid with 2006–2007 financial market buoyancy and the current economic uncertainty are a mirror of the model conditions presented in the Skyscraper Index:9 a tool used to forecast the potential economic downside of building tall. When London’s current tall building market conditions are overlaid, there is an almost perfect match. This infamous index historically demonstrated that tall building construction follows the peak of a country’s economic cycle and is followed by a significant economic slump.25 This index was previously thought to be unable to predict the UK tall building market as it was based on US economic cycles and while its logic stood for historic cycles, it
unsuccessfully predicted the last two US economic slumps (the last of which was 9/11 driven), owing to changing investment criteria and expectations as the index was conceived in 1999.

However, this research shows that the recent history of London’s tall buildings shows strict correlation to the Skyscraper Index. London’s office market suffered downturns in 1974, 1982, 1990 and 2002. The two most recent falls were marked by the construction of London’s best-known skyscrapers: Canary Wharf tower in 1991 and 30 St Mary Axe in 2003. As previously proposed, the average gestation period (from proposal to completion) for a UK tall building is eight years and each economic cycle lasts for some ten years. This makes it virtually impossible to get the timing right on tall buildings.26

It is apparent from this research that the current suite of tall buildings being constructed in the heart of the City, (122 Leadenhall, the London Bridge tower, Heron tower, 20 Fenchurch Street, the Bishopsgate tower or Pinnacle and the Broadgate tower) which were all commissioned in the mid to late 1990s, are due for completion between 2008 and 2011. If the Skyscraper Index is to be believed, the current uncertainty in the UK economy will degenerate into a full-blown recession as these buildings are nearing completion over the next few years.

7. CONCLUSION
This paper has investigated the evolution of the UK tall building, and has determined the reasons behind this building form’s growth at previously unprecedented rates. A definition has been created of the UK tall building and it has been compared with the international tall building stage. The types of demand have been analysed and four subsectors of UK tall building market have been categorised. The value of the UK tall building construction market has been calculated, its growth potential has been forecasted and the latest negative market developments during 2008 have been discussed, warning of the current match of the UK market to the Skyscraper Index model and the resulting risk of full-blown economic recession.

The findings of this research will become more relevant as the market hardens. Builders of tall buildings will increasingly need to refine their approach to potential clients based on the four demand types explained here and tailor the build approach for each form of tall building. Speculative fat, thin/ iconic and mixed-use tall building developments will be the first to disappear, while those being built with an element of pre-let have a longer forecast and may be able to ride out the current economic uncertainty. Residential towers, which have not yet started on site, will be held back in increasing numbers until the current month-on-month residential price drop stabilises and the bottom of the market is seen to be reached.

Tower cranes across the London’s skyline have traditionally been a highly visible measure of the health of the construction industry as well as an accepted indicator of the strength of the UK economy as a whole. If the view from the City to St Paul’s is unblemished by Wolf’s, Liebherrs and Potaïns, then a slump is on the horizon.27 If this indicator is to be believed, then the London tall building market is thriving as almost 30 tower cranes were counted on 1 January 2009 from London’s St Pauls.

At the other end of the forecast spectrum, if the Skyscraper Index is to be believed, then both the UK tall building and whole economic outlook is dire. Arguably one of the world’s most enduring famous tall buildings, the Empire State Building, closely followed the index’s prediction. On completion it was nicknamed the Empty State Building owing to its low occupancy rates until after World War II. Sales publicity for the building claimed the feeling of looking out from its viewing gallery was better than air travel. It was not publicised that the viewing platform was only built because the office space could not be sold.28 Will the UK’s tall building momentum stall, will London’s skyline soon be host to a myriad of sky-high, empty viewing galleries, or will the UK’s new tall buildings continue ever upwards, unbending in the current economic storm (see Figure 8)?

REFERENCES
1. See www.cityoffices.net.
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APPENDIX B PAPER 2

INTRODUCTION

1.1 Preceding research

The paper by the same author titled ‘Tall Building Boom – Now Bust?’ established that Britain’s recent demand for tall buildings was of an unprecedented high level, directly comparable in size to America’s Manhattan Island skyscraper boom of the 1920’s, but that the construction market was ultimately heading for a recession, this second paper determines the global state-of-the-art of building tall buildings. This has been achieved by designing a questionnaire which captures the most pressing issues of the tall building process, targeting the questionnaire at the most active specialist tall building professionals around the globe, then delivering these questionnaires face to face, resulting in an 80% response rate. The results give great insight to the consensus of professional opinion across the globe and across the specialist sectors of the industry. This paper investigates five key areas: the current state-of-the-art of the international tall building industry; the build process of a tall building; the tall building principal contractor key attributes; ‘wins’ and ‘losses’ inherent with building tall and new techniques from overseas or other industries. The paper offers a clearly signposted way ahead for innovative construction of tall buildings.

ABSTRACT:
Following on from the author’s first published paper titled ‘Tall Building Boom - Now Bust?’ which concluded that Britain’s recent demand for tall buildings was of an unprecedented high level, directly comparable in size to America’s Manhattan Island skyscraper boom of the 1920’s, but that the construction market was ultimately heading for a recession, this second paper determines the global state-of-the-art of building tall buildings. This has been achieved by designing a questionnaire which captures the most pressing issues of the tall building process, targeting the questionnaire at the most active specialist tall building professionals around the globe, then delivering these questionnaires face to face, resulting in an 80% response rate. The results give great insight to the consensus of professional opinion across the globe and across the specialist sectors of the industry. This paper investigates five key areas: the current state-of-the-art of the international tall building industry; the build process of a tall building; the tall building principal contractor key attributes; ‘wins’ and ‘losses’ inherent with building tall and new techniques from overseas or other industries. The paper offers a clearly signposted way ahead for innovative construction of tall buildings.
analysis of the results, correlating industry specialist sector per geographical region, drawing out con-
trasts and trends between specialism and geographical location in the global tall building industry and
isolating areas of global innovation in tall building construction that could be beneficially applied to the
UK tall building industry.

The objective of this paper is to investigate five key areas of the global tall building industry:
The current state-of-the-art of the international tall building industry;
The international build process of a tall building;
The tall building principal contractors key features;
Wins and losses inherent with past tall building projects;
New techniques from overseas or other industries.

The analysed results lead to some surprising con-
clusions, but offer a clearly signposted way ahead for the innovative construction of tall buildings.

1.2 Pilot interviews and questionnaire development

The research for this paper initially involved un-
derstanding the specific issues associated with build-
ing tall, firstly on a UK basis, then expanding this to
a global view. This stage commenced with a litera-
ture review, followed by targeted structured inter-
views held with the four most prolific tall building principal contractors in the UK. These interviews
gave shape, direction and provided specialist insight to the tall building process, risks, experienced ‘pro-
ject losses’ and some innovative ‘project wins’, plus signposted some areas demanding further develop-
ment. This stage was followed by a series of pilot questionnaires, tested on academic and professional colleagues, each version being further refined and tailored to capture the most pressing issues of the tall building process. This ultimately led to the de-
sign of the ‘State of the Art of Building Tall Questionnaire’, issued by hand at Dubai and London tall building conferences and on the American Council on Tall Buildings and Urban Habitat website: 
http://www.ctbuh.org/Research/Overview/Constructi

The final questionnaire design captured qualita-
tive and quantitative data, aimed at building a com-
prehensive picture of the global tall building indus-
try. The respondents targeted for the questionnaire were the most active and high profile specialist tall building professionals around the globe, all attend-
ing or presenting at the Council of Tall Buildings and Urban Habitat (CTBUH) 8th World Congress, held in March 2008 in Dubai and the New Civil En-
gineer’s ‘Engineering Tall Buildings September
2008 Conference’, held in London. The results gained from over 150 questionnaire responses are
presented and discussed in this paper.

2 THE QUESTIONNAIRE

Questionnaire responses were gained from five
tall building industry sectors, representing a cross section of specialists in the global tall building in-
dustry: The tall building End User or Client; The tall building Investor or Developer; The tall building Design Team Member or Con-
sultant; The tall building Specialist Contractor or Sup-
plier; The tall building Principal Contractor.

A minimum of five and maximum of ten re-
sponses from each of the five specialist sectors were gained for each of the four geographical areas con-
sidered, resulting in a good representation of the global tall building industry.

The questionnaire was split into six sections, the
first five sections addressing each of the five tall build-
ing key areas and the sixth capturing respond-
ent’s professional details, including current tall building project type, name and their industry spe-
cialist sector. The analysed responses to each section are presented below.

2.1 Section 1. International tall building industry –
current state-of-the-art

This section set out to establish an overview of the
tall building industry across the globe and the key issues inherent in building tall buildings.

The results showed that the majority of respon-
dents from all specialist sectors and locations be-
lieve that:
The international construction industry is not keeping pace with the latest, cutting edge design developments in tall buildings;
The UK construction industry is not keeping pace with overseas construction industry develop-
ments;
The UAE has the most innovative construction industry, followed by China, the USA, Japan, Australia and the UK (joint), then Korea;
The global demand for tall buildings will con-
tinue to grow;
The ‘iconic’ tall building form will take over from the more traditional, rectilinear form;
The tall building format provides a sustainable future for the growing global population;
The sustainability or ‘green image’ of a tall build-
ing is growing in importance;
The sustainability of the construction process of a tall building is not as important as that of the finished building; Safety is of paramount importance in the construction of tall buildings; Falls from height are recognised as a large contributor to health and safety incidents in the construction of tall buildings; A more innovative build approach should be sought to minimise falls from heights during the build process.

2.2 Section 2. The build process of a tall building

This section investigated the build process of a tall building, wherein respondents rated fourteen risks inherent with a tall building project.

‘Principal contractor staff experience’, ‘inclement weather (winding-off tower cranes)’, ‘specialist trade procurement’ and ‘defects completion and handover for progressive occupation’ were consistently ranked the highest risk. These were followed by ‘logistical problems (man and material access, hoist / crane strategies)’, ‘superstructure cycle times / speed of erection’, ‘façade installation’, ‘services installation / commissioning’ risks. The next series of risks were ‘lift installation / builders use / commissioning’, ‘roof / waterproofing / cleaning / specialist architectural features’, ‘shell & core interface with fit-out works’. The lowest rated risks for the tall build process were perceived as ‘demolition of existing building / site clearance’, ‘ground conditions / foundations’, followed by ‘substructure construction’.

This section also investigated the respondent’s desire for innovation in tall building construction and their experience of structural frame build speeds, a critical-path activity of every tall building. It concluded that the majority of respondents would strongly embrace and promote innovative construction approach on their tall building project, over a tried and tested construction technique (the example given was the potential use of an innovative crane accessory reducing the effect of wind on material lifts). It also found that the majority of respondents believe a typical tall building concrete frame can be built one floor to the next floor (floor cycle time) averaging 2-4 days. The majority of respondents also believe a typical tall building steel frame can be built with an average piece rate (number of pieces of structural steel erected per crane per day) of 16-20 pieces.

2.3 Section 3. Tall building principle contractors

This section investigated the tall building principal contractor, wherein respondents rated statements regarding experiences of procuring a tall building project principal contractor, the perceived inherent benefits and most desired attributes.

The results showed that the majority of respondents believe that:

Tall building principal contractors offer a poor level of safety analysis and value analysis (buildability) of the design at preconstruction stage; Involving the principal contractor at an early stage in the tall building design does assists in delivering value, safety, programme and cost certainty;

Procurement route options are severely restricted on tall buildings due to the limited number of high quality, capable principal contractors;

Construction Management is currently the preferred procurement route for a tall building principal contractor and this form will continue to grow in favour;

Previous tall building experience is critical in the selection process of a principal contractor for a tall building project.

This section also showed that Construction Management and Two Stage Lump Sum forms of Contract were the two most widely used forms to enter in contract with the tall building principal contractor on the respondents ‘live’ tall building projects.

Respondents were then asked to rate the importance of nine inherent tall building project risks previously disseminated from the structured interviews held with the four most prolific tall building principal contractors in the UK. The results showed that the majority of respondents believe that ‘securing finance’, ‘construction programme surety’ and ‘cost control / certainty’ were the three highest risks. These were followed by ‘the design process meeting expectation’, ‘securing tenant pre-lets’, ‘build quality’ and ‘construction safety’. The lowest risks were seen as ‘declining demand for tall buildings’ and ‘regulatory and statutory requirements’.

Respondents were then asked to rate the importance of principal contractor key attributes that they would consider in selecting the principal contractor for their tall building project. The most important attribute was the ‘provision of an experienced tall building team’. This was followed by ‘lowest cost’, ‘innovative build approach’, ‘history of programme certainty’, ‘logistics management efficiency’, ‘procurement expertise’ and ‘local knowledge and experience’. Mid-rated attributes included ‘history of cost certainty’, ‘design management ability’ and ‘value management ability’. Lower ranked attributes included ‘safety record’, ‘established supply chain’, ‘political connections’ and ‘rank or position held in the construction industry’. The least important attribute was the ‘ability to offer project funding’.
2.4 Section 4. Wins and losses inherent with building tall

This section investigated respondent’s experience of tall building project ‘wins’ or ‘losses’. ‘Wins’ were defined as things that were done well on a tall building project that significantly contributed to the success of the construction process. ‘Losses’ were defined as things that were not done well on a tall building project that negatively contributed to the construction process.

This section was not completed in 20% of the responses. However, of the 80% completed, the qualitative responses were highly varied, relating to management techniques or systems, technological advances such as innovative material or methods, plus design related wins and losses. However, the majority of both wins and losses related to the perceived skills of the tall building project team.

The most repeated tall building project win was regarding a high quality construction and management team, with tall building experience from around the globe. The second most repeated win was the early involvement of key trade contractors or specialist suppliers, positively influencing the cost, buildability and programme surety. Good and consistent team communication on project issues such as cost, programme and design drivers was also a recurring theme. Five recurring types of innovative construction methods were also captured, including slipform advances, tower-crane / hoist advances, concrete related advances and delivery phasing or staging related advances. The majority of these technological wins came from respondents across the five specialist sectors who were directly involved with super-tall towers in the UAE.

The most repeated tall building project loss was regarding a perceived low quality construction and management team, lacking tall building experience and skills. Noted weaknesses or specific areas where mistakes had been made included: poor management of the design team; poor trade contractor and supplier procurement; underestimating cost (inadequate budget), design complexity and programme; lack of understanding of efficient construction methods and techniques (relying on trade contractor knowledge, rather than in-house expertise).

2.5 Section 5. New techniques from overseas or other industries

This section investigated new or innovative techniques or practices witnessed by the respondents, which could be adopted in the construction process of a tall building project. These ideas could be either from overseas construction methods, other industry practices, or simply areas where the traditional building approach seems outdated and in need of a fresh approach. It was completed by 80% of respondents, whose observations covered a wide range of topics. They covered aspects from each project phase from detailed design development, through construction to completion, handover and occupancy of the tall building.

A selection of the most radical and potentially most beneficial from each project phase include:

- Design development – A Dubai mixed use tall building utilised early specialist input to influence the design to incorporate a structural ‘jump start’ at Level 8. This allowed the construction works for this section of building to run early, in parallel with the lower levels;
- Construction and completion – the Leadenhall Building in London developed a ‘bottom-up’ demolition of the existing building to allow an early start on excavation and substructure construction. (see Fig 1 and 2);
- Handover and occupancy – An Australian residential tall building in Melbourne developed a phased completion strategy accepted by the statutory authorities, allowing early sectional completion, occupation and easing project cash flow.

Figure 1. Leadenhall Building, London. Bovis Lend Lease bottom-up demolition
Section 6. Respondents details

This section captured the respondent’s professional specialist sector, or discipline, within the tall building industry, categorised as: the tall building End User or Client; Investor or Developer; Design Team Member or Consultant; Specialist Contractor or Supplier; and lastly the tall building Principal Contractor.

This section also captured the type of tall building project the respondent was currently involved with, showing that the majority of respondents were working on ‘Commercial / Office’, followed by ‘Residential’, then ‘Mixed Use’ tall buildings. It also captured the respondent’s geographical location, their organisation / company, and the name of their current tall building project. Although the last two sets of information remain confidential, it is relevant to note that responses were gained from specialists involved with the majority of the current set of iconic tall and super tall buildings currently under design and construction in USA, UAE, London, Paris, Italy, Vietnam, Korea, Japan, Australia and across China.

This information will allow further analysis of the responses to be undertaken, investigating the correlation of each industry specialist sector across each geographical region, drawing out contrasts and trends between specialism and geographical location in the global tall building industry and isolating areas of global innovation in tall building construction that could be beneficially applied to the UK tall building industry.

3 DISCUSSION

The analysis undertaken for this paper created a unique snapshot of the global state-of-the-art of the tall building industry over the first to third quarters of 2008. It captured the industry’s buoyant mood and strong belief in continual growth in demand for tall buildings, especially for iconic tall buildings and its unexpected thirst for innovation in the build process over tried-and-tested approaches. It reflects the industry’s growing desire for sustainability in tall buildings, if not in the construction process itself. A high level of appreciation of safety risks associated with building tall was common across all industry sectors and recognition of falls from heights as a primary cause of incidents on tall buildings.

It also shows that the industry’s leading practitioners believe that the construction industry is not keeping pace with cutting edge designs for tall buildings. This may be reflecting a frustration on the Design Team, Consultants and Client’s perspectives that their iconic designs cannot be constructed as cheaply or quickly as the more traditional rectilinear designs for tall buildings.

From a UK perspective, it highlighted some surprising results as the UK was deemed not to be keeping up with overseas construction industry developments and was ranked as joint sixth out of seven countries for an innovative approach to construction. This shows the industry as a whole and particularly the UK needs to increase the level of innovation in the tall building construction process.

The risk rated the highest in the tall building process was the provision of experienced principal contractor staff, showing the majority of the industry feel they are under-resourced with skilled, experienced tall building professionals. This was mirrored by responses in the principal contractor section, where it was strongly felt that procurement route options were restricted due to the limited number of high quality, capable tall building principal contractors globally. This theme was also reflected by the top rated principal contractor attribute being ‘provision of an experienced tall building team’. Additionally, the most common tall building ‘win’ was related to a high quality construction and management team, and most common ‘loss’ was related to a poor quality construction and management team, lacking tall building experience and skills. The recurring theme of the responses throughout each section of the questionnaire point to an overheating tall building construction market during the first three quarters of 2008, with insufficient skilled resources to cover the unprecedented demand for tall buildings.

It is interesting to note that the declining demand for tall buildings was seem as the lowest of nine tall building risks across all industry sectors and geographic locations. Clearly, in the first to third quarters of 2008, the industry specialists did not foresee the Skyscraper Index (Lawrence 1999) about to bite. (this infamous index historically demonstrates that tall building construction follows the peak of a country’s economic cycle and is followed by a significant economic slump).

4 CONCLUSIONS

This paper has satisfied the objective of investigating five key areas of the global tall building industry, across four main geographical areas of Europe, UAE, USA and Asia Pacific:
It has established the current state-of-the-art of the international tall building industry;
It has captured key features of, and ranks perceived risk in the international build process of a tall building;
It rates the desired tall building principal contractor’s key attributes;
It has captured ‘wins’ and ‘losses’ inherent with past tall building projects;
It has captured new ideas and techniques from overseas and other industries, potentially bringing benefit to the UK tall building industry.

This initial analysis of the results lead to some surprising conclusions, but offers a clearly signposted way ahead for the innovative construction of tall buildings. This paper will be followed up by a more in-depth analysis of the results, correlating industry specialist sector per geographical region, drawing out contrasts between industry specialism and geographical location in the global tall building industry. This further research will also focus on isolating areas of global innovation in tall building construction that could be beneficially applied to the UK tall building industry along with areas clearly needing further innovation to improve the current state-of-the-art.

5 REFERENCES


APPENDIX C PAPER 3
Abstract: This paper builds on previous research by the authors which determined the global state-of-the-art of constructing tall buildings by surveying the most active specialist tall building professionals around the globe. That research identified the effect of wind on tower cranes as a highly ranked, common critical issue in tall building construction. The research reported here presents a design for a “Lifting Wing,” a uniquely designed shroud which potentially allows the lifting of building materials by a tower crane in higher and more unstable wind conditions, thereby reducing delay on the programmed critical path of a tall building. Wind tunnel tests were undertaken to compare the aerodynamic performance of a scale model of a typical “brick-shaped” construction load (replicating a load profile most commonly lifted via a tower crane) against the aerodynamic performance of the scale model of the Lifting Wing in a range of wind conditions. The data indicate that the Lifting Wing improves the aerodynamic performance by a factor of up to 50%.

Keywords: aerodynamic; wind tunnel; tower crane; tall building; construction; innovation.
1. Introduction

The primary concern in the engineering of tall buildings is the effect of the wind on the building’s structure. Each uniquely shaped section of the world’s tallest tower (Burj Dubai) prevents the wind from becoming organised and limits lateral movement [4].

The Lifting Wing applies this fundamental engineering concept to the actual build process of a tall building and its life blood, the tower crane.

Previous research undertaken for “Britain’s Tall Building Boom: Now Bust?” [17] and “The State of the Art of Building Tall” [18] provided a unique snapshot of the Britain’s unprecedented demand for tall buildings in first quarter of 2007 to end of 2008 and the global state-of-the-art of the tall building industry over the first to third quarters of 2008. This research captured the industry’s buoyant mood and strong belief in continual growth in demand for tall buildings, especially for those of “iconic” design. It also captured the industry’s unexpected thirst for innovation in the build process over tried-and-tested approaches. The four key results were:

- The international construction industry is not keeping pace with the latest, cutting-edge design developments in tall buildings, and that the UK construction industry is not keeping pace with overseas construction industry developments;
- “Inclement weather (winding-off tower cranes),” consistently ranked one of the two highest construction risks, followed by “logistical problems (man and material access via hoist and crane),” “superstructure cycle times/speed of erection” and “façade installation,” all directly related to wind and its effect on the tower crane;
- Tall building experts believe “construction programme surety” and “cost certainty” were the two most significant risks of a tall build. The most important attribute of a principal contractor was determined as “innovative build approach and the provision of an experienced tall building team,” followed by “history of programme certainty,” “logistics management efficiency,” reinforcing the industry’s thirst for innovation, as well as desire for logistical, programme and therefore cost certainty;
- Eighty percent of tall building experts interviewed would strongly embrace and promote the use of the innovative construction technique that reduces the effect of wind on tower crane material lifts on their tall building project.

The conclusion of that paper’s research was that there was strong international desire for an innovative solution to critical construction problems, the most highly ranked of which was wind negatively affecting the build. Paired with the key desire of programme certainty and hence cost certainty, this clearly signposted that an innovative concept was needed to mitigate delays to the tall building programme duration by reducing the effect of wind on the critical path activities of the tower crane. This focused the final stage of the research on the design and testing of an innovative concept named the “Lifting Wing,” aimed at directly addressing this industry need.

This paper describes the scientific advancement in applying aerodynamic theory, refined via modelling and testing, to a specific aspect of the building process of a tall building with potentially significant time and commercial benefits. The specific research undertaken in design, modelling and methodologically testing an aerodynamic shroud, was aimed at reducing the wind-induced load on a
tower crane and the construction material being lifted, thereby allowing lifting in higher wind conditions, reducing the UK average of 40% down time for a tall building tower crane. This would therefore potentially reduce very costly wind-induced critical path delay to a tall building construction period.

1.1. Wind and its Effect on Tower Cranes—The Life Blood of the Tall Building

Tower cranes have come to symbolize the construction industry and perform an indispensable service in moving material components horizontally and vertically to their required positions. They are central to mid- and high-rise building projects [15]. They have become internationally recognised as a highly visible gauge of a city’s economic growth. In the UK, if the view of London’s skyline from the city to St Paul’s Cathedral is unblemished by Wolff, Liebherr and Pontain cranes, then a slump is on the horizon [10]. In the US, the popularity of tower cranes has been slower to develop; however, in 2006, Miami was named “Crane City,” as over 300 tower cranes were estimated to be working [16].

It is universally recognised that the tower crane’s main weakness is the debilitating affect that high or gusting wind conditions can have on their ability to perform their critical construction role, hence there is a risk of delay to the tall building programme through a drop—or even halt—in the construction productivity rate. This delay can have huge commercial and reputational consequences for the builder if a tall building project is not completed and handed over in accordance with the construction contract dates.

There have been many technical advancements in computerisation, communication and control of tower cranes, the latest of which are integral to new cranes and available as retro-fit kit for older cranes [14], all aimed at improving productivity and safety. However, there have been no advancements aimed at the crane’s oldest adversary—wind. The Lifting Wing aims to address this imbalance.

Wind forces exerted on the lattice structure of a tower crane and the construction load suspended from the crane hook directly affect the ability to safely operate and control a crane and its construction material load. The higher the wind speed, the greater the force exerted on the crane and load, and the greater the likelihood of having to shut down crane operations and hence site productivity on programme critical activities drops. The force exerted is wind pressure, caused by air particles travelling at speed and hitting a stationary object—in this case, the crane structure and its bulky suspended load. Wind pressure varies as the square of wind speed. Therefore, if wind speed doubles, the wind pressure increases by a factor of four. A relatively small increase of wind speed can therefore have a significant effect on the safe lifting operations of a tower crane.

Tower cranes are designed to international standards that specify the “in-service” wind speed that a crane must be able to withstand and operate safely. These are typically 14 m/s (31 mph) for mobile cranes and 20 m/s (45 mph, Beaufort Scale Gale Force 8) for tower cranes [8]. However, the reality of the construction site is that the Tower Crane Operator will decide to take the crane out of service at a wind speed significantly lower that the manufacturer’s prescribed “out of service” speed, due to their increased difficulty in safely controlling the crane. This is recommended practice in the UK crane industry [5]. The primary reason for the inability to control the crane is due to the effect of the wind pressure on the construction load being lifted, rather than the crane structure itself. Wind pressure acting on the load suspended at the end of the tower crane’s lifting cable results in increasing difficulty
for the operator controlling the crane’s operations of lift, swing, travel, lowering and landing of loads on a congested construction site. This causes a significant safety risk, not only for the crane operator, but for any operatives in the vicinity of the crane and its load. This effect results in the crane ceasing operations at relatively low wind speed with a relatively frequent occurrence, hence critical path programme activities are commonly delayed.

1.2. The Effect of Wind on Suspended Loads

Strong winds tend to gust rather than blow consistently. This is amplified in tall building
construction site locations which are generally in, or adjacent to, built-up clusters in city centres.
The neighbouring buildings tend to break up the relatively smooth flow of wind over open land and
cause turbulent or separated flow. This turbulent flow of air across a tower crane and its load can result
in an induced rotating (yaw) and swinging motion (drag caused by a gusting wind) on the suspended
construction load, pushing it out of balance, increasing the radius from the centre of gravity of the
crane and therefore the overturning moment on the crane, potentially making the tower crane unstable.
For a relatively light load with a large surface area, such as formwork shutters for concrete frame
buildings, steel floor pans for steel frame buildings or cladding panels, this situation will occur
significantly below the tower crane’s design wind speed.

For example, a wind speed of 14 m/s (30 mph) generates a wind load on a 2.5 m × 1.3 m (8 ft × 4 ft)
standard formwork shutter of 372 Newtons (N). If the wind speed increases by circa 50% to 20 m/s
(45 mph), the wind load rises to 740 N an almost 100% increase of load. If this wind blows from
behind the crane, the load radius will be significantly increased, potentially overloading the crane. For
example, a formwork shutter weighing 750 kg with an area of 3.25 m² and suspended on a 27 m cable
will move 1.4 m from the vertical when subjected to a 14 m/s (30 mph) wind. Moving the load radius
by this distance on a 35 tonne capacity crane with a 34 m main boom working at 18 m radius would
reduce the rated capacity from 950 kg to 640 kg. If this occurs close to the lifting and radius limit of a
tower crane, the result could be a catastrophic crane collapse.

This has occurred many times across the world with disastrous effect, the most famous of which is
“Big Blue,” a giant Lampson Transi-Lift crane that collapsed due to the effect of wind on its load
whilst building Miller Park, the Milwaukee Brewers Stadium, USA [12], which was recorded by the
Occupational Safety & Health Administration safety inspector on site the day of the collapse [11]. It
had a rated capacity of 1500 tonnes and was lifting a load of 450 tonnes, well inside its maximum
capacity. Upon investigation by independent specialist bodies, the concluded primary factor of the
collapse was the high wind load acting on the section of roof being lifted and lack of consideration of
those loads on the crane’s rated capacity [13].

2. Hypothesis

Conclusions from the earlier published paper summarised above [18] which signposted a
widespread demand for innovation in the area of wind and its negative effect on the construction
process, along with research undertaken in aerodynamic theory and site observations of the effect of
wind force on a suspended load of a tower crane on many of the authors’ construction projects, led
to the idea of reducing the effect of this force by sheathing construction materials in an aerodynamic
profile during lifting operations. This would reduce the wind force effect on the load, create more stable flight characteristics, ultimately reducing the loads imposed on a tower crane and thereby increasing the ability to lift safely in challenging wind conditions.

Various profiles were investigated to achieve the best compromise of two diametrically opposed requirements: that of an aerodynamic shape and the ability to allow large and irregular shaped construction materials to be encapsulated within the aerodynamic profile. A section of an aerofoil (a two-dimensional wing) in a horizontal orientation was ultimately selected, as established aerodynamic research shows that at low approach angles the air flow is able to follow the curve of the upper and lower surfaces of the aerofoil closely, then join smoothly towards the trailing edge, minimising eddies [2]. There remains a relatively high pressure region at the front, but the low pressure at the rear is much closer to atmospheric pressure, resulting in a resistance (coefficient of drag, CDrag) that is around 20 times less than a flat sheet and 10 times less than a cylinder profile [9]. CDrag is a dimensionless quantity that is used to quantify the drag or resistance of the Wing in air. The lower the CDrag, the less aerodynamic drag on the surface of the shape.

Figure 1 is a view from above a section of aerofoil and shows the smooth flow of air from left to right over the streamlined shape, but that flow separation occurs progressively as the aerofoil is turned at an oblique angle to the air flow (yaw angle). The Lifting Wing aerofoil design aims to prevent this “stall” effect by being freely suspended from the tower crane lifting cable, ensuring it is free to rotate and remain “nose to wind,” presenting the minimal surface area to the prevailing wind direction, thereby minimising the effect of wind on the tower crane suspended load.

**Figure 1.** Increasing flow separation as yaw angle increases [9]. (Reprinted with permission from [9] Copyright 2012 Prentice Hall).

As an aerodynamic ideal, the Lifting Wing design would follow a slim, streamlined aerofoil profile with a sharp trailing edge [7]. However, the practical consideration of ensuring typically large
construction loads can be accommodated inside the profile outweighs the desire to reduce the drag (Cd) to an absolute minimum level. This results in an aerofoil profile that is wider than the ideal, but still aerodynamically efficient.

2.1. NACA Foil Design

The National Advisory Committee for Aeronautics (NACA) conducted extensive research into aerofoils from the 1930s, some of which are still utilised in aircraft manufacturing [1]. They are defined by four-digit wing sections:

- The first digit describes the maximum camber as percentage of the chord (the line between the leading and trailing edges);
- The second digit describes the distance of maximum camber from the aerofoil leading edge in tens of percent of the chord;
- The third and fourth digits describe the maximum width of the aerofoil as percent of the chord.

The XFOIL programme [6] was utilised to review 2D aerofoils between NACA 0012-50 to determine the most suitable profile that when extrapolated into a 3D shape would achieve a balance between aerodynamic efficiency and sufficient width to accommodate an array of typical construction load dimensions.

NACA 0035 (00 indicating that it has no camber, 35 indicates that the aerofoil has a 35% width to chord length ratio) was ultimately selected as the profile most suitable for the Lifting Wing design, balancing length and width to accommodate the largest, most commonly lifted tall building construction loads. An analysis was undertaken of materials most commonly lifted in the construction of typical concrete and steel-framed tall buildings. This analysis showed that metal floor pans or decking used as permanent formwork for concrete floors in the majority of steel-framed tall buildings, plus timber formwork, bundles of structural steel or concrete planks for concrete framed tall buildings (both commonly 1.2 m wide and up to 5 m long) can be inserted within the profile which would have a chord length of 6 m at full scale. The selected profile would also comfortably accommodate typical individual or loose loads such as mechanical and electrical services components, concrete kibbles and skips, edge protection screens, and palletised or bagged loads such as blocks, sand and cement. At full scale, the selected profile would accommodate these most commonly lifted items, whilst offering a relatively narrow frontal area, smooth flow path around the flanks to minimise flow separation and a sharp trailing edge to minimise drag and side forces otherwise exerted on the load and transferred to the crane.

2.2. The Lifting Wing

The full-scale Lifting Wing described by the NACA 0035 aerodynamic profile would be 6 m long × 2.10 m wide by 2.0 m high, built of a lightweight, high impact resistant clear plastic skin over a stiff, skeletal frame. It would be open at the top and bottom to allow it to be lowered over the load and for access to the lifting chains. It will be hung with three-point lifting chains attached to the crane hook and lowered by crane over the construction materials to be lifted. The load is then propped/strapped inside the Wing, restraining the load’s position relative to the Wing. The Wing fully encapsulates the load, which is directly suspended from the hook of the tower crane. The Wing profile
then gives the load an aerodynamically efficient, predictable and more controllable profile in high wind speeds. A smaller version would be made to accommodate smaller loads such as palletised and bagged loads, 3 m long and 1.5 m high.

Following established aerodynamic theory, the Wing would reduce the key drag load and pitching moment (which would cause the suspended material to swing fore and aft on a crane rope), along with side force and yaw (which would cause lateral oscillation of the lifted material) induced by the wind forces acting on the load being lifted. This is diagrammatically shown in Figure 6. The reduction of the effect of these wind-force-induced loads and a more stable “flight” of the lift should result in safer lifting of construction materials in higher and gustier wind-speed conditions than the current industry standard. The ultimate objective is to reduce the industry-accepted norm of 40% “down time” for the tower crane over the construction phase of a tall building due to “winding off.” This would thereby save time on the critical path of the tall building construction programme and, hence, substantial costs. This theory was then tested by building a scale model of the Lifting Wing for wind tunnel testing.

3. Aerodynamic Testing

3.1. Aim of the Testing Programme

Tests were conducted at Loughborough University’s open circuit wind tunnel, the layout of which is shown in Figure 2 and the scale of which can be determined from Figure 4a. The aim was to compare the aerodynamic performance of a scale model of a typical rectangular, “brick”-shaped construction load (replicating a load profile most commonly lifted via a tower crane) against the aerodynamic performance of the scale model of the Lifting Wing in a range of wind speeds and yaw angles. To ensure the test results are predicative of full-scale results, the tests were planned to be undertaken with a Reynolds number (Re) as close to the calculated full-scale Wing, Re of $8.2 \times 10^6$, calculated for a wind speed of 20 m/s, where $Re = \frac{\text{Inertia Force}}{\text{Viscous Force}} = \frac{(\text{Density} \times \text{Velocity} \times \text{Length})}{\text{absolute coefficient of Viscosity}}$. If the model has the same Re as the full-scale application, then they are dynamically similar [3]. The non-dimensional function of Fluid Viscosity, Density, Pressure, and Temperature will be the same for the model and full scale. However, Re sweep tests of both models showed the Re became invariant above $1.5 \times 10^6$, allowing the results obtained to replicate the full-scale Lifting Wing in wind speeds of up to 90 mph (current international standards for tower crane “in-service” wind speeds with no aerodynamic aid are up to 20 m/s or 45 mph).

Figure 2. Loughborough university aeronautical and automotive engineering wind tunnel isometric.
3.2. Testing Method

The scale model of the Lifting Wing was built to an accuracy of ±1 mm, with the design based on the NACA 0035 aerofoil. The chord length was 600 mm, maximum width of 216 mm and height 200 mm, with a cross-sectional area of 0.0432 m$^2$. This equates to a 1:10 scale model of the full size Lifting Wing. The model construction was formed using a 2 mm-thin plywood sheet laid over and fixed to a slim CNC cut plywood spar frame at the top and bottom of the wing, as shown in Figure 3a,b.

**Figure 3.** (a) Lifting Wing model and top mounting bracket; (b) Wing internal void, spar frame and brackets.

Similarly, the 1:10 scale model of the typical construction load, the “Brick”, was built with the same technique, having a chord length of 600 mm, maximum width of 210 mm and height of 200 mm, giving a reference area of 0.043 m$^2$.

It was initially anticipated that multiple sets of results would need to be taken, depending on the accuracy and repeatability of the obtained results. However the first series of test results showed good accuracy and repeatability (within 5%) and a minor, but consistent level of asymmetry. This test series was run twice allowing the arithmetic mean to record the central tendency. The asymmetric tendency was subsequently determined as a feature of the tunnel and had been repeated in numerous wind tunnel test experiments undertaken by Aeronautical Researchers at Loughborough University and was quantified and accounted for, therefore deemed to be insignificant to the results.
The wind tunnel test allowed quantitative data for drag, pitch, side force and other relevant forces acting on the Brick model and the Wing model at a range of wind speeds and yaw angles to be compared. These forces and their directional impact on the Wing are shown in Figure 6. These tests were conducted in parallel with flow visualisation observations at key stages of the testing to cross check the quantitative results and the logic behind conclusions drawn. Additionally, a preliminary dynamic test was also undertaken as a third method of cross checking results obtained from the first two methods, giving qualitative information in the form of a visual display of the Wing under freely suspended conditions reflecting, as closely as possible, the conditions of the full-scale Wing suspended by a tower crane. However, results obtained were indicative only, due to issues with model symmetry and difficulty finitely levelling the model. The dynamic test will be refined and re-run in the next stage of research.

3.3. Test Summary

The objective of this test was to generate quantitative data for the model’s drag (C\textsubscript{d}), lift (C\textsubscript{l}) and pitching (C\textsubscript{p}) moments at varying degrees of yaw and wind speed. The wind tunnel test was designed to minimize systematic errors by considering and compensating for the most likely causes of error including model or tunnel asymmetry, error caused by the wind forces acting on the connection shaft between the model and the tunnel balance, plus random errors. The method of testing involved both the reference “Brick” model and the Lifting Wing being rigidly fixed by a steel connection shaft to the balance (Figure 4b), which is fitted into the floor of the working section of the tunnel. Once true zero (head-to-wind) position was established by undertaking a yaw sweep for each model, the tests were undertaken for each model in turn. The reference areas of the models, the wind speed, barometric pressure, air temperature, drag, lift, side-force, pitching moment, yawing moment and rolling moments, plus their coefficients, were recorded by the tunnel computer data logger at a range of wind speeds from zero to 40 m/s. The model was then rotated (yawed) on the balance through two degrees away from true zero and all measurements recorded. This was repeated by further 2\degree increments up to ±20\degree, then 1 degree increments up to a maximum of ±25\degree yaw. Tests for each model were re-run after powering down the wind tunnel (effectively re-setting, or zeroing the tunnel and its data logger) to determine the repeatability of results. All results taken were within 5\% of the initial result with no outliers, allowing the arithmetic mean to be utilised for the final result. Measurements for the Wing were compared to the reference Brick model, ultimately demonstrating the aerodynamic improvement of the Wing.

Figure 4. (a) LU AAE Wind Tunnel Bell-mouth and Exhaust; (b) Balance below Tunnel Working Section.
3.4. Test Method

- The steel connection shaft was mounted to the tunnel balance and the wind tunnel was run at 5 m/s increments from zero up to 45 m/s to determine forces due to shaft alone and allow balance results for each model to be adjusted for shaft effects. To refine these results, a replica support shaft of the same diameter as the one used to support each model was raised into the tunnel to a height of 450 mm. Each model was then attached to the tunnel roof via the original support shaft and lowered until it was just clear of the replica shaft fixed to the balance. This gave a more accurate balance reading of the shaft value to be subtracted from each model measurements;
- The Brick model was mounted on the steel shaft fixed to balance. The maximum velocity, $V_{\text{max}}$ was established by running wind tunnel from 0 m/s at 5 m/s incremental speeds, whilst ensuring drag, lift, side-force, pitch, yaw and roll loads did not exceed 90% of the limit of the wind tunnel balance. This was repeated for the Wing model, resulting in a $V_{\text{max}}$ of 40 m/s, with generated forces at just over 85% of the balance limit for the Brick model;
- A Reynolds Number (Re) sweep for the Brick at zero degrees yaw, over incremental wind speeds from 0 to 40 m/s was run allowing the calculation of the Re for the range of wind speeds, plotted to determine the minimum wind speed at which the Re becomes a constant (thus replicating full-scale results). This was repeated for the Lifting Wing. Resulting Re values shown in Figure 5, demonstrated that above Re of 600,000 there is relatively little Re effect and results are as close to full scale as possible;
- A series of tests for both the Brick and Wing were run, recording forces graphically shown in Figure 6, the results of which produced following graphs: Brick Yaw Angle versus CDrag for 30 m/s and 40 m/s; Brick Yaw Angle versus CLift for 30 m/s and 40 m/s; Brick Yaw Angle versus CSideforce for 30 m/s and 40 m/s; Brick Yaw Angle versus CPitch for 30 m/s and 40 m/s; Wing Yaw Angle versus CDrag for 30 m/s and 40 m/s; Wing Yaw Angle versus CLift for 30 m/s and 40 m/s; Wing Yaw Angle versus CSideforce for 30 m/s and 40 m/s; Wing Yaw Angle versus CPitch for 30 m/s and 40 m/s.

Figure 5. (a) Brick Re versus Cd; (b) Wing Re versus Cd.
3.5. Test Results

An overlay of the two crucial sets of results for the Wing and Brick Yaw Angles versus CDrag at 30 m/s and 40 m/s, and the Wing and Brick Yaw Angles verses CLift at 30 m/s and 40 m/s were graphically plotted, shown in Figure 7a,b.

The primary conclusions drawn from the CDrag overlay of the Wing and Brick are:

- The Wing profile had a dramatically lower overall drag profile (in excess of 50% less CDrag than that of the Brick), hence significantly less drag load would be induced on the cable and the crane, in all wind conditions;
- The Brick results plotted graphically exhibit a deep V, which shows a relatively large sensitivity to wind direction changes, which dramatically increase drag- and swing-induced loading, hence load on the crane. This feature is shown by comparing flow visualisation Figure 8a at zero degrees showing a wide flow attachment line one third back from the nose and Figure 8b at 10 degree offset, showing a more defined flow attachment line further forward, directly behind the front corner. This increases the size of the wake area and reverse flow behind the Brick, thereby increasing drag;
- By comparison, the Wing plotted results exhibit a smooth, shallow curve, showing relative insensitivity to changes in wind direction, with less drag- and swing-induced forces, hence a more stable flight. This is demonstrated by comparing the Brick Figure 8b and the Wing Figure 11a at 10 degree offset. This shows smooth attachment lines running to the sharp trailing edge of the Wing, limiting the separated flow, or wake area behind the Wing, hence low drag;
- The tendency for drag to increase as yaw angle increases tails off earlier with the Wing, reaching a maximum at around ±12° (See Figure 7a) due to the sharp trailing edge and smooth flanks, whereas the Brick drag forces continue to increase as yaw angle increases to a maximum at around ±18° as the wake area behind the Brick and reverse flow continues to grow. This demonstrates the improved stability generated by the Wing, reducing drag-imposed loads on the crane in higher wind speed and with changeable wind directions.

The primary conclusions drawn from the CLift overlay of the Wing (with Brick load inside the Wing) and Brick are:
• Lift forces generated on both models are less than a 10th of magnitude of drag forces and therefore its influence is likely to be less significant;
• The Wing profile has a lower overall lift profile (less than 1/4th of the lift of the Brick at higher yaw angles) hence significantly less rise-and-fall load would be induced on the cable and crane in higher wind conditions. This feature is most clearly demonstrated by comparing flow visualisation Figure 9a, the leeward side of the Brick at −25°. It shows a more pronounced flow along the top and bottom edges, which become more dominant at the higher yaw angle. In contrast, the Wing (Figure 12a) shows the leeward side of the Wing at −10° (which was almost identical to the Wing at −25°). The Wing shows more fractured, multiple flow separation lines running from the nose toward the tail that drop away much earlier. These markedly differing flow features would explain the differing lift forces generated on each model;
• The Brick exhibits a sharp and deep W profile, which signifies sensitivity of this shape to increasing wind yaw angle, dramatically increasing lift- and fall-induced loading, hence load on the crane. This would result in a rotation of the load when freely suspended from a crane, causing safety issues when trying to fly and land the load safely;
• The Brick also shows increasing sensitivity to higher wind speed as the results for 30 m/s and 40 m/s diverge at higher yaw angles producing unstable flight characteristics as these factors increase;
• By contrast, the Wing exhibits a smooth, shallow curve, showing relative insensitivity to changes in wind yaw angle or wind speed, hence less rise- and fall-induced forces and more stable flight characteristics.

Figure 7. (a) Wing and Brick Yaw Angles versus CDrag for 30 m/s and 40 m/s; (b) Wing and Brick Yaw Angles versus CLift for 30 m/s and 40 m/s.
3.6. Wind Tunnel Test Conclusion

Each of these tests were run twice and results showed good repeatability of generated quantitative data for both model’s drag and lift forces at varying degrees of yaw and wind speeds. The arithmetic mean was taken to give the central tendency as there were no outlier results taken (all values were within 5% of the initial the result). Side force and pitching moment were also measured in this method, but ultimately deemed less critical, being relatively similar for both models, with slightly less pitching moment generated by the Wing under extreme yaw angles and slightly higher side forces generated by the Wing at higher yaw angles, creating a restoring yawing moment (self-correcting characteristic), ultimately producing a stable flight in changing wind direction. These mean results demonstrated significantly improved aerodynamic characteristics of the Wing, resulting in significant reductions in critical forces generated by wind acting on the Wing, hence forces imposed on the tower crane at full scale. These results point toward the Wing assisting the tower crane operator in their control of the tower crane in higher wind-speed conditions experienced on a construction site, thereby delaying his decision to take the crane out of service at a wind speed significantly lower that the manufacturers prescribed “out of service” speed.

These conclusions were further tested by conducting flow visualisation analysis of the Wing and Brick at varying wind speeds and yaw angles in the wind tunnel, discussed below.

3.7. Flow Visualisation

A series of flow visualisation photographs of the Brick and Wing models were taken at key stages in the wind tunnel testing for each model to allow comparison of aerodynamic flow around the models. These were achieved by coating the Brick and Wing models with a mixture of titanium dioxide, paraffin and linseed oil, and capturing the resultant flows at true zero degrees, plus and minus 10° and plus and minus 25° yaw at varying wind speeds. A demonstrative selection of flow images are given in Figures 8–12. Wind is flowing from left to right in all figures with exception of 11a,b, where it is right to left. Windward is a (+) yaw angle from true zero (head-to-wind flow), showing the side facing into the wind and leeward a (−) yaw angle showing the side in the wind “shadow”.

Figure 8a is a flow visualisation photograph of the Brick at true zero to the wind flow and is viewed from the leading edge corner. The wind flow impacts on the flat face and spreads out towards all four sides of the Brick. The flow separates at the four edges and a large wake is formed behind the Brick. This wake is responsible for the large coefficient of drag seen in the wind test results. The wide flow separation line running from the top to bottom of the Brick at the point where the vortices at each side of the Brick, created by the blunt nose, reverse the flow back toward the front of the Brick where it meets the wind flow spilling around the nose corner and become entrained in the wake. This causes the flow to stall and gravity then drags the mixture down. These flow patterns should occur on all four sides (excepting gravitational effect).

Figure 8b, taken from the same position, but with the Brick at +10° yaw (windward), shows the reverse flow separation line being pushed much nearer the front corner of the nose. This is caused by a more dramatic meeting of the vortex flow (which has increased force due to the +10° yaw) and the frontal flow spilling around the nose corner. It also shows flow detachment approximately mid-way
along the Brick, with some flow being pushed toward the nose and some being pushed toward the rear of the Brick.

**Figure 8.** (a) Brick at $0^\circ$, 40 m/s; (b) Brick at $+10^\circ$, 40 m/s.

![Figure 8](image1)

Figure 9a shows the leeward side of the Brick at $-25^\circ$ yaw. There is more pronounced flow along the top and bottom edges, which becomes more dominant at the higher offset angle. The flow has separated at the edge on the front face, but the reverse flow is now three dimensional, flowing towards both the front and side edges. The flow towards the sides meets flow spilling around from the top and separates at the white line and is entrained into the wake. The separation line at the lower edge is smaller due to gravity. This will contribute to the lift force seen in wind test results. The resulting wake will be more pronounced on this side.

Figure 9b shows the windward side of the Brick at $+25^\circ$ yaw. The flow is pushing from the front centre in three dimensions toward the top, bottom and rear trailing edges remaining attached along the flank. The resulting wake will be less pronounced on this side.

**Figure 9.** (a) Brick nose at $-25^\circ$, 40 m/s; (b) Brick tail at $+25^\circ$, 40 m/s.

![Figure 9](image2)

Figure 10a shows the Lifting Wing model at $0^\circ$. The Wing has a very low aspect ratio and the flow around the trailing edge is highly significant. The extent of the separated flow producing the wake is much smaller than for the Brick, resulting in a significantly lower drag. The flow is attached from the nose and forms two strong flow separation lines running from the nose toward the tail. These drop away toward the bottom rail at the tail of the Wing as flow rate reduces and gravitational forces take over. The collection of mixture at approximately one third along from the nose of the Wing.
is at its widest point. This may indicate a nearing of flow separation at this potential transition point, but the flow successfully negotiates the curve of the Wing and continues in laminar flow along the Wing’s surface until it nears the tail’s trailing edge.

Figure 10b shows this effect from the tail view. It shows the flow reducing as it runs along the Wing and gradually falling under gravitational force as it nears the narrowest point, the trailing edge. It then separates, creating a relatively small wake.

**Figure 10.** (a) Wing nose at 0°, 40 m/s; (b) Wing tail at 0°, 40 m/s.

Figure 11a shows the Wing at +10° yaw, where it exhibits a more singular flow separation line running from the nose toward the tail. This drops away more gradually, only hitting the bottom rail at the tail intersection point. The collection of mixture has moved further back from the nose of the Wing and is now behind the point of maximum Wing width. This indicates the potential transition point has moved further back due to the increased windward yaw angle, hence increased flow across this face of the Wing. Again, it does not actually separate at this point and continues toward the tail in laminar flow until it nears the tail trailing edge, but at a point further from the tail, indicating that the turbulent boundary layer is occurring earlier. The flow patterns are very similar to the 0° case which explains why the drag appears to be relatively invariant for the Wing.

Figure 11b shows this effect from the tail view and shows the flow reducing and falling under gravitational force as it travels to the trailing edge, but that it separates earlier to become turbulent flow.

**Figure 11.** (a) Wing nose at +10°, 40 m/s; (b) Wing tail at +10°, 40 m/s.

Figure 12a shows the Wing at −10° yaw, leeward side viewed from the nose. The Wing now exhibits more fractured, multiple flow separation lines running from the nose toward the tail that drop
away much earlier, demonstrating that the flow rate is much reduced across this face and gravitational forces take over earlier. The collection of mixture has moved further toward the nose and is now in front of the maximum Wing width position. This indicates the transition point has moved forward due to the more turbulent, reduced flow formed in the wind shadow. It now actually begins to partially separate at this point, whilst some flow does continue toward the tail in laminar flow but then separates at a point much closer to the midpoint of the Wing, indicating that the turbulent boundary layer is occurring much earlier. This effect would create the restoring turning moment in the Wing, ensuring it returns to a zero yaw position (nose-to-wind).

Figure 12b is the tail view and shows the flow reducing and falling under gravitational force much earlier as it travels along the Wing and separates earlier to become turbulent flow across the rear third of the Wing.

Flow visualisation pictures of the Wing at ±25° yaw showed no significantly differing patterns to the ±10° discussed above. This fact demonstrates that the drag is relatively invariant for the Wing, whilst exhibiting significantly less drag variation than the Brick.

![Figure 12. (a) Wing nose at −10°, 40 m/s; (b) Wing tail at −10°, 40 m/s.](image)

### 3.8. Flow Visualisation Conclusion

These flow visualisations show a relatively clean, stable flow over the Wing at varying degrees of yaw, demonstrating stable and predictable aerodynamic behaviour. The significantly reduced drag of the Wing compared to the Brick, along with the Wing’s invariance of drag at higher yaw angle, are the key factors in proving the ability of the Wing to operate safely in higher and gustier wind conditions than a standard construction load. These observations correlate with the quantitative data taken during wind tunnel testing and reinforce the characteristics of stable and improved aerodynamic behaviour of the Wing over the Brick. These results were further tested by conducting a dynamic test of the Wing suspended in the wind tunnel.

### 3.9. Preliminary Dynamic Test

The objective of this dynamic test was to conduct visual analysis of the Wing’s aerodynamic characteristics under conditions reflecting, as closely as possible, suspension of the Wing from a tower crane cable in wind conditions likely to be experienced on a tall building site. No
quantitative measurements could be taken during this test, as it was purely a visual analysis of the Wing’s aerodynamic performance.

It was noted during this test that error in model symmetry and the inability to finitely level the model affected the results and would need further refinement to achieve an accurate replication of full-scale results.

The Wing model was freely suspended by three, 2 mm in diameter multi-strand steel cables, each with a 10 kg breaking strain. These were mechanically fixed to the top edge of the model, one directly above the centre of the nose and two equally positioned on the top edge either side of the Wing, behind the widest section of the Wing. The centre line of the three wires were over the centre of gravity of the model. These wires were sufficiently long to allow the Wing to be suspended in the centre of the tunnel working section, with the wires running through a hole in the roof of the tunnel and mechanically fixed externally to support the dead and live loads of the model during testing (Figure 13a). This suspension method replicates the envisaged method of suspension of the full-scale Wing from a tower crane.

A series of videos were taken to record the behaviour of the Wing under increasing wind speeds from 0–12 m/s. These tests were then repeated with loads added inside the Wing (1 kg metal plates fixed inside the wing profile) to replicate 1, 2 and 3 tonne loads on a full-scale Wing (Figure 13b). Observations were made on Wing stability and flight behaviour from the side and roof windows of the tunnel working section.

Figure 13. (a) Wing Suspended for Dynamic Test; (b) Wing with Internal Load.

3.10. Dynamic Test Observations

The test was initially run with no internal load and videoed from the side window of the tunnel. The Wing remained relatively static as the wind speed was increased from 0 m/s to 9 m/s, swinging
slowly back by approximately 5° from the vertical as wind speed increased to 9 m/s. At 10 m/s the nose of the Wing was observed to begin to move horizontally from left to right, stop and then return from right to left through the head-to-wind at 0° yaw. This repeating oscillation increased in yaw angle as the wind speed was increase to a maximum of 12 m/s, whereupon the nose of the model, viewed from above, moved left to right whilst swinging forward and back, describing a repeating infinity (∞) movement over a distance approximately equal to half the length of the model (300 mm). This oscillation reduced as the wind speed was reduced to 9 m/s, whereupon the model became relatively static again, holding the 5° inclined position.

This test was repeated with a load of 2 kg fixed inside the Wing. It repeated the pattern of the first test, with the exception that the oscillation began at the increased wind speed of 11 m/s and diminished as the wind speed was reduced below 11 m/s.

Finally, a load of 3 kg was fixed inside the Wing, again repeating the pattern of the first and second tests, with the exception that the oscillation began at an increased wind speed of 12 m/s and diminished when wind speed was reduced below 12 m/s.

The initial movement of the nose from left to right was deemed to be caused by a lack of absolute symmetry of the model and it being slightly out of level horizontally due to unequal lengths of its three suspension cables. These small errors create a gradually increasing turning moment on the model as the wind speed increases. However, this also demonstrates the Wing’s self-correcting characteristic, producing stability of flight at full scale, as this would ensure a slowly correcting nose-to-wind position of the Wing, desirable in changeable, gusty wind conditions typified on congested city-centre tall building sites.

3.11. Implications of Results on Wing Design

This preliminary dynamic test demonstrated that the full-scale Lifting Wing would need to be made symmetrically, ideally utilising vacuumed formed thermoplastic technology or moulded carbon-fibre-reinforced polymer, plastic or thermoplastic giving the added benefits of a higher strength-to-weight ratio and greater ability to withstand impact deformation. Residual error could be corrected by adding a top mounted vertical stabilising fin, fixed above the trailing edge of the Wing. The dynamic test also demonstrated the need for finite adjustment of suspension cables to ensure truly level flight. Following this paper’s publication, this dynamic test will be further refined by the introduction of turnbuckles on each of the three suspension wires above the tunnel, allowing finite adjustment of each cable length, and hence achieving true horizontal suspension of the model in the tunnel.

This test also demonstrated the proportional relationship of increasing load to more stable flight—the greater the load carried inside the Wing, the less effect the non-symmetrical features of the model had on the stability of the flight in increased wind speed. It also proved that the ultimate wind speed in which stable flight could be achieved would be directly related to the size of the load carried inside the Wing.

4. Overall Conclusions

The wind tunnel test quantitative data correlates with the flow visualisation and preliminary dynamic test observations. These reinforce the primary Wing characteristics of reduced drag in excess
of 50% lower than the Brick and of side forces on the Wing creating a restoring moment when flying in changeable wind direction conditions, giving a desirable nose-to-wind behaviour. These key characteristics combine to reduce induced loads on the tower crane and produce stable improved aerodynamic behaviour of the Wing when compared to typical construction loads.

This demonstrates that the Wing achieves its primary purpose of increasing the ability to lift construction materials safely in higher and more gusty wind-speed conditions than is currently achievable. Therefore, the Lifting Wing design, if used on a tower crane of a tall building, should create a valuable contribution in mitigating the effect of wind causing critical path delay during the construction of a tall building, potentially reaping substantial time and cost savings. This knowledge and benefit could be transferable internationally as, without exception, tall buildings across the world are built using tower cranes which are negatively affected by wind during the build period, delaying completion, frustrating builders from completing on time and budget and ultimately, owners from occupying their new tall buildings. These positive results will be further demonstrated by future studies utilising a full-scale Lifting Wing on a tower crane, discussed in the following section.

5. Further Work

Following running the refined dynamic test discussed above, the final stage of the Wing development will be undertaken with assistance from the authors’ sponsoring company involving the construction of a full-scale Wing and its dynamic testing utilising a Saddle Jib or Luffing Jib Tower Crane. In this test, an experienced tower crane operator will lift a rectangular “Brick”-shaped reference load in wind conditions approaching industry-recognised winding-off speeds. The load will then be placed inside the full-scale Wing and lifted in the same wind conditions. The operator will note flight characteristics of each lift and determine the increased wind speed in which the Wing can still be lifted safely. This qualitative analysis will rely on the feedback from the operator, rather than on any measured force data. However it is exactly this operator analysis that is used across the industry to determine the safe limit of lifting by cranes on every site the world over. If tower crane operators feel the Wing allows extended lifting in higher wind conditions, then it will have succeeded.

An international patent has been applied for covering the Lifting Wing and the research that has been undertaken to date.

Author Contributions

This paper describes an element of the doctoral research conducted at Loughborough University in partnership with Lend Lease for the award of Engineering Doctorate. Ian Skelton was the Research Engineer and undertook the majority of the primary work. The co-authors of this paper are the EngD supervisory team, augmented as the project progressed due to staff movements. All supervisors contributed to manuscripts as the paper was being developed and reviewed. Peter Demian was the principal supervisor from the beginning of the project. Jacqui Glass was the second supervisor at Loughborough University at the time the experiments for this paper were conducted and the paper was written. Dino Bouchlaghem and Chimay Anumba were supervisors during their time at Loughborough University, and remained active contributors after moving to other organisations.
Conflicts of Interest

The authors declare there are no conflicts of interest.

References


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Defining a Tall Building in the UK

This research focuses on tall buildings in the UK as being between twenty to sixty stories, circa 80 – 300m (depending on whether the building has commercial or residential floor to floor heights). A good definition of a tall building in town planning terms is one which stands above the prevailing skyline. A good construction definition is a building which has technical and design differentiation from its neighbours. Even with modern build methods, above twenty stories a building becomes technically distinct in its structure, services, vertical circulation, life safety and cost. This is why they deserve a different classification – the UK tall building.

Research undertaken for this review shows that of the fifty eight current UK tall buildings currently proposed, almost 70% are in London. This report therefore focuses on London, but does consider the South East and Other Regions.

London High Rise = Global Mid Rise

London’s skyline is predominantly low rise with distinct pockets of medium to high rise, planned to allow space for the protected St Paul’s Cathedral sight lines from strategic London viewpoints (Planning Act 1990). A tall building in the London context is considered to be twenty to sixty storeys. At the top end of the London scale are London Bridge Tower (the Shard) and The Bishopsgate Tower topping 300m and containing more than eighty storeys. The lower end of the London scale is dictated by the need at this height for technological changes to the way buildings are constructed, utilising tall building techniques as opposed to low rise construction techniques.

New York City is widely recognised as one of London’s main competitors for the status of financial centre of the world. Its skyline, in comparison to London, is predominantly medium rise with widespread pockets of high rise. A tall building (skyscraper) here is deemed to be thirty to one hundred plus stories (although local fire codes change at fifteen storeys). In the last six years America’s appetite for commercial tall buildings has cooled, but residential demand remains strong and international developments are beginning to influence corporate decision-making in New York, especially regarding sustainable design. The future of the skyscraper seems assured in New York City, even after the loss of nearly three thousand lives in the Twin Towers disaster of Manhattan. Manhattan has showed resilience as a business location, according to recent research conducted for the Russell Sage Foundation: three years after the attacks, financial firms have mostly decided to stay in Manhattan. Even Cantor Fitzgerald, a trading firm that lost two-thirds of its employees in the collapse of the World Trade Center towers, will move into new quarters in midtown (Fuerst 2007). These businesses, according to a recent New York Times report, are now spending $3.8 billion annually on security and disaster contingency planning. The key factor for financial firms influencing the decision to stay ‘in the hub’ is the importance of access to sensitive knowledge through face-to-face interaction and a tightly woven network of personal relationships between
industry professionals, Clients, suppliers, and other decision-makers. America’s other largest cities of Chicago, Washington and Los Angeles are also consolidating their global-hub status. The idea that businesses must cluster ‘downtown’ as they do in London had seemed ‘quaint’ in America. The assumption was that technology would liberate workers from the inconveniences of the congested centre, but the business location decisions post 9/11 seem to disprove this.

American tall building developers and large tenants have resisted the thin ‘Euro towers’ typified by small floor plates and bespoke cladding systems. Americans argue this form of tall building is costly and not enough people can gather on a single floor. A design such as Swiss Re’s 30 St Mary’s Axe would not be feasible in America due to the lower importance placed on internal spatial quality and external sculptural effect, plus the widespread availability of large, regular shaped building plots in the US. Floor plates are deeper and more efficient in America, where core to wall depths of 13-18m (42-60’) are standard. Due to the bigger floor space per height, American tall buildings are financially more efficient. Less constrained sites in the UK such as Canary Wharf allowed tall buildings to follow the American model (although on a shallower floor plate depth).

Tokyo is the second main competitor to London for the status of financial centre of the world. The skylines of Tokyo, Hong Kong and Shanghai cities, in comparison to London’s, are predominantly high rise with isolated pockets of low rise on the peripheries. Asia is seen as the natural environment of the very tall building. These very tall buildings make sense where density and the urban infrastructure make it the most effective way to occupy land. High density living is already an accepted norm in much of Asia. Towers are constantly being built in Hong Kong, Guangzhou, and the other high-growth Asian cities. The tallest, densest Chinese buildings are rising over rail stations, with airport access, (Willis, 2007). As the Chinese population continues with rapid industrialisation, there is a boom in tall buildings on an unprecedented scale. China has at least sixty two, three hundred metre buildings, or ‘supertalls’, at some level of development - there are nine in Chongqing alone, which means it is building more 150m tall towers now than New York has ever built. This is extraordinary as every major Chinese city is undergoing a similar scale of development in an organic and market driven manner, rather than following the property speculation bubble model that Dubai followed. Dubai is impressive in its construction of tall buildings, but China is growing an equivalent of ten Dubai’s.

The UK tall building is therefore defined on the international stage by its more conservative height, individual architectural approach to the internals and externals, its response to its non-regular site and the surrounding heritage of the city-scape. This results in high quality, individualistic buildings demanding high quality building solutions. Modularity and repetition are not seen as UK tall building traits, resulting in a more costly solution.

The Rise and Rise of Tall Buildings in London

Britain’s experience of tall buildings has long been in the shadow of post-war regeneration. The 1950’s to 1970’s produced a swathe of local authority housing towers and brutalist office towers between ten and thirty storeys high. The high-profile failure of these post war experiments due to weak design, detailing and construction led to a general rejection of the high rise form in the 1980’s and a concentration on the conservation and heritage arenas. There were a few exceptions to this rule in the first generation of tall buildings. The notably successful
tall buildings of this era have now achieved listed building status: Centrepoint (Grade II), BT Tower (Grade II) and Trellick Tower (Grade II*).

Interest in tall buildings has risen to new heights recently, both in the commercial and residential sectors. This is evident on the supply side, especially in London, where a pro tall building stance is notable in: The London Plan; the number of planning proposals for tall buildings; the granting of planning consent to new proposals such as Heron Tower, the Shard in Southwark and Columbus Tower in Tower Hamlets; the recent completion of numerous tall buildings in various London locations including Paddington, The West End, The City and Canary Wharf; the successful refurbishment of previous generations of tall buildings such as Tower 42 and City Point. Signature architects are now falling over themselves to design tall buildings (Strelitz 2005).

There is now a strong City ambition to build high. Davis Langdon & Seah International believe this has grown from Foster and Partners mould breaking design for the owner-occupied Swiss Re development, which won support from CABE (Commission for Architecture and the Built Environment), English Heritage and the City, all of whom were keen to secure bespoke headquarters for major commercial institutions (Morrell, 2006). The high profile success of Swiss Re’s 30 St Mary’s Axe undoubtedly led to increasing pressure for more towers. The Heron Tower Inquiry followed and forced the evolution of city policy, developing the concept of an ‘Eastern Cluster’ in the city, not affected by St Paul’s Cathedral Height Grid, Strategic Viewing Corridors or Conservation Areas (Linklaters, 2002). 122 Leadenhall Building will become the focal point of this new cluster.

The rising profile of London as a ‘World City’ over the past decade (LPAC 1998), allied to the refocus of the planning system for high density developments and brown field schemes, have assisted this growth in building tall. London, now seen as the de-facto capital of Europe and is consolidating its position of a world leading financial centre, second only in trade value to Frankfurt. It has desires to eclipse Frankfurt as Europe’s financial-services capital. Some experts believe this is already happening as it has more people with more skills, depth and expertise in one spot than any other in Europe (Duffy 2007). The London Mayor believes London is now challenging Tokyo and New York as their only global competitor. He has repeatedly stated this must be underpinned by the provision of world class office space and infrastructure. ‘London must continue to reach for the skies’ (Livingstone, 2001).

Globally, property has enjoyed a re-rating as an asset class and London particularly has benefited. Jones Lang Lasalle believes London is vying with New York as the world’s premier financial centre as a result of tighter financial regulation in the US and a growing reluctance in the Middle East to invest in America post 9/11 (Jones Lang Lasalle Research 2006). Savills Research foresees a resurgence in institutional investment activity in London residential stock due to its ‘more benign regulatory environment’ and the continued globalisation of property markets. UK funds are being benchmarked against other countries where residential is already a mature investment sector. The relatively strong and stable UK performance produced over the last ten years in comparison to other asset classes will continue to act as a draw to more funds in the future (Savills Research, 2007).

The current suite of tall buildings being constructed in the heart of the City (Leadenhall, Shard, Gerkin, Heron, Fenchurch St. and the Bishopsgate Tower) were all commissioned due to the threat of London Docklands on the City’s position in the mid 1990’s. Plot ratios were relaxed to encourage development in the City. This response
to a ten year old threat is now visible on the streets even though the threat has gone as Canary Wharf is now 90% full (McAlister, 2006). The latest development in this office turf-war between the City and the Docklands is that of global advertising agency Ogilvy & Mather being in advanced talks to move back to central London from Canary Wharf. They were the first tenants to move to Docklands in the late 1980s and are interested in a refurbishment of the former GLC headquarters at County Hall (Hodgekiss, 2007). The prestige of the City seems to be coming back into effect according to cityoffices.net, an independent property advisor to the property market. Figure 1 shows the huge area of office space under construction in the seven sectors of London in Q4 of 2006.

![London Offices Under Construction, Q4 2006](image)

<table>
<thead>
<tr>
<th>London City Sectors</th>
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<tr>
<td>City</td>
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<tr>
<td>City Fringe</td>
<td>54,440 sqm - (585,988 sq ft)</td>
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<tr>
<td>West End Fringe</td>
<td>67,351 sqm - (724,960 sq ft)</td>
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Figure 1. London City Office under Construction, Q4, 2006 (cityoffices.net 2007)

**Evolution of London Policy for Tall Buildings**

Research shows a recent rise in public interest in tall buildings has coincided with a change in policy and the emergence of widespread support, which has been dormant for over twenty years. Tall building-proactive policy changes include:
- Central Government now believes that tall buildings meet with their current focus on sustainable development, satisfy their urban renaissance requirements of increased density and could help toward the reduction of private car commuting, thereby assisting with the ‘Kyoto Objectives’.

- The Government has stated that ‘high rise buildings generally require smaller sites than low rise buildings with big floor plates offering an equivalent amount of space’ (Linklaters, 2002).

- The Government recently encouraged local councils to generate proactive policies toward tall buildings and identify suitable and non-suitable sites in their local plans.

- The Government’s support of tall buildings has been proven recently with the Deputy Prime Ministers approval of planning consent for London Bridge Tower and Heron Tower.

- The Government re-established a strategic planning authority for London in 2000. The GLA superseded the London Planning Committee in 2000 and published the London Plan in February 2004: ‘London must cater for its projected population growth to 8.1 million people by 2016, with 636,000 new jobs being created over this period in order to maintain its status as a Global City. It must do this without sacrificing London’s open spaces and green belt. To achieve this objective, tall buildings are identified as mechanisms to facilitate increased densities at locations with good public transport’ (GLA, 2004).

- All London Authorities are now required to bring their local plans into broad compliance with the Mayor’s London Plan (Strelitz, 2005).

- New powers were granted to the Major of London in July 2006, which allow the Mayor to approve ‘strategic’ planning applications, although ministers have yet to fully define the meaning of ‘strategic’. The Mayor will also be able to override local consultations on planning policies and order boroughs to conform to his planning priorities.

- Many London Local Authorities are now actively supportive of tall buildings, arguing that they promote economic development (such as Corporation of London, Westminster and London Boroughs of Southwark, Croydon and Hackney.

- The Mayor advised ‘there are only a limited number of strategic locations where tall buildings are viable and there are strict guidelines which developers and planners must meet. Tall buildings are likely to be built in small clusters, like Canary Wharf, where the surrounding infrastructure can support them’ (Bar Hilley, 2006).

- The Commission for Architecture and the Built Environment (CABE) replaced the Royal Fine Arts Commission in 1999. CABE is a non-statutory planning consultee that champions quality architecture and urban design. It published jointly with English Heritage (also a statutory consultee) the ‘Guidance on Tall Buildings’ in 2003 which forms part of the policy that tall building proposals are judged against. Together they have backed tall buildings deemed to be in ‘the appropriate site and achieving architectural, urban and economic benefit’. (CABE 2003). In January 2007, CABE and English Heritage published a consultation draft of their newly-updated Guidance on Tall Buildings, which has been updated to reflect changes to the planning system and the experiences CABE and English Heritage...
have had in evaluating planning applications for tall buildings. Additionally, CABE publicly backed the proposed 20 Fenchurch St on the eve of its public hearing, stating it is a fine investment in architecture, a world class design and changes its environment for the better.

- The most potentially damaging recent development for tall buildings was the replacement of John Prescott as Secretary of State at the Department of Communities and Local Government in October 2006. This caused problems for the tall building as his replacement, Ruth Kelly, rejected planning permission for Rafael Vinoly’s Fenchurch St Tower and Ian Simpson’s Brunswick Tower as her first move in office. English Heritage had not asked for an inquiry on either tower and the developer, Land Securities, believed John Prescott would have approved the shorter 20 Fenchurch St proposal. This change of stance may be due in part to the comments made by UNESCO Inspection Team about the unsuitability of oversized developments adjacent to the World Heritage sites of Liverpool’s docklands and The Tower of London (Dorrell, 2006). The Government is currently undertaking a study to determine if these strategic viewpoints need more protection against tall buildings – this will potentially be at odds with the London Plan and cause further debate. Fortunately for the tall building market, Kelly has been recently replaced by Hazel Blears, who appears to have a more tolerant tall building approach, although this may be tempered by her calling in of Lambeth’s 140m high Doon Street Towers in October 2007 in response to English Heritage and CABE’s concerns over sight lines.

Who’s Driving Demand for London Tall Buildings?

Two distinct occupiers of tall office buildings in London have been identified by previous research and are driving demand for two types of tall buildings (LPR, 2001 & Insignia Richard Ellis Research, 2002). However, this research has identified two additional occupiers:

The first is large corporations relocating to a single building requiring ‘fat’ towers with floor plates of 3000m$^2$ gross and up to 5000m$^2$ total area. Their relocations are planned amalgamations of various operations, creation of synergies between business units and to reduce facilities management costs. Examples are HSBC, Citygroup, and Barclays, who moved to Canary Wharf as it offered the right mix of floor plate, quality of space, size and critical mass of complementary businesses. These types of offices are now achieving an average rent of £70 per sq ft across the seven London fringes (EGi, 2007).

The second is small international companies demanding a prestige location in multi-tenanted tall ‘iconic’ buildings. Their floor plate requirement is between 1500 – 2000m$^2$ gross. They value prestige, high quality shared facilities and opportunities for interrelations with neighbouring businesses. This is shown by low vacancy rates and high rental yields. These types of offices are now regularly achieving £100 per sq ft across London, a new record set during the second quarter of 2006 (EGi, 2007).

A third, emerging tall building market is the mixed use tower, incorporating residential, retail, office and hotel. This form shows signs of increasing its high density tall building market share. These schemes can be inherently efficient with complimentary structural requirements and heating and cooling shares between different occupiers’ systems, (McAlister, 2006). This specialist tall building is discussed further in this review under ‘Mixed Use Comes of Age’.

The fourth tall building demand is the residential market, reviewed separately in this report.
Based on the research undertaken for this report, the current tall building market split for London is 54% commercial towers (fat and iconic), 28% residential towers and 18% mixed use towers, shown graphically in Figure 2.

![London’s Proposed Tall Buildings](Image)

London’s Proposed Tall Building Demand.

The sum of these four markets means that London’s demand for tall buildings is at an unprecedented level. Sixteen of the twenty-six tallest structures in London are currently in the detailed design or construction phase (Morrell, 2006). Additional delivery pressure is being brought by the looming 2012 Olympics, which forms a small part of the construction planned in and around the capital constituting £5 billion of the £20 billion estimated budget. The Olympics has become an artificial deadline for a large number of projects, which causes consolidation of work (Thompson, 2006). This has proven to be the case with a number of tall buildings currently being worked on with Bovis Lend Lease. There is concern that these large projects running concurrently with the Olympics will overheat the construction market, creating local shortages of skilled labour and materials, forcing up prices by a factor of 20% for steel reinforcement and concrete costs according to EC Harris. Davis Langdon’s Market Forecast Report for 2007 summarises that the top and bottom of London’s market is polarising, whereby large projects are suffering from greater inflationary pressures, while smaller schemes retain a more competitive edge (Fordham, 2007).

Tall Commercial and Mixed Use Demand

Demand for tall buildings will be bolstered by the recent sale of 30 St Mary’s Axe, Swiss Re’s 41 storey tower, which set a record for a UK office at £600m, bought by UK investment bank Evans Randell and German fund manager IVG Immobilien, realising a profit of circa £250m for Swiss Re (even though it is famously inefficient as an office with only 60% net lettable area). This sale was rapidly followed in the property press by Tishman’s potential sale of the 36 storey City Point Tower at £650m and HSBC’s sale and lease back of its docklands tower at circa £800m. The latest in these tall building purchases was in early March 2007, when Arab Investments Ltd purchased the rights to the proposed 288 metre tall Bishopsgate Tower from DIFA for £200 million. The record profits made by these sales are good omens for the continued demand for tall buildings as a profitable investment.
EGi, the independent research consultants and owner of The London Office Database are forecasting a flurry of further property deals throughout 2007 as property companies that have delayed signing until after the introduction of Real Estate Investment Trusts (REITs) now complete. Many property companies have themselves become REIT’s to maximise tax advantages, British Land amongst the first batch. These deals reinforce the commercial property boom which started early in 2005. King Sturge’s Head of Research reports the amount of foreign finance looking to invest in London is unprecedented – ‘as if people are not so much investing in London, as buying London’ (Independent 2007). King Sturge put the 2006 investment in the City alone, not including the Docklands and West End as £8.5billion, up from £6billion in 2005.

Jones Lang Lasalle record the volume of office space taken up by new occupiers rose by 1.1million sq ft, an increase of 35% from 2005 to 2006. This is the highest rate of growth since 2000 in the City. Rental rates in the City grew by 20%, in 2006 but the West End grew 27% driven by banks, investment houses, private equity and professional services firms expanding and regularly exceeding the £100 per sq ft barrier (Cityoffices.net 19-01-2007). Vacancy rates have dropped from 18% in 2005 to 3-4% in 2007. They forecast another three or so years of 10% growth in the London office market assisted by ‘the London growth storey’, the transparent market and relatively long leases offered.

Savills Commercial Research Ltd summed up 2006 by publishing investment returns for the year on offices as 23% against 17% in industrial and 15% in retail. They expect the strong office performance to continue driven by rising demand and falling vacancy rates across London and the South East which will push the regional cities to make significant progress.

This is reflected by predictions made by Davis Langdon at the February Economic Forecasting Conference. They stated that 40% of all new orders placed in the UK in the last 9 months (from May 06 - Feb 07) were for London offices, driven by the availability of London floor space dropping below demand. This has created a two to three year window before there is a return to an overhang (supply of office space exceeding demand). This gives ‘an unprecedented development portfolio in terms of scale, with many of these schemes to be towers’ (Rawlinson, 2007). This sharp increase in quantity of office space commencing construction is shown in Figure 3, with over 100,000 m² started in the City in Q4 of 2006, the highest in the last six years. Figure 3 also shows the growth profile, or trend, since 2003.
Tall Residential Demand

The renaissance of tall residential buildings is due to increasing house prices outstripping build cost inflation and the rising profile of ‘city living’ as a desirable lifestyle. This has led to a relatively new phenomenon of a price premium relative to the height of the development. Residential property in London is some of the most expensive in the world, with the record being taken in March 2007 by the luxury Candy & Candy development, One Hyde Park. It is a high density four block by twelve storey scheme, which achieved £4200 per sq ft when the first penthouse sold for £100m. (The Times January 2007). The writer subsequently won the fit out contract for this Penthouse at £35m, making it the most expensive home per square foot in the world. In the lower market levels, many inner and outer London boroughs have reported values over £400 per sq ft, only achieved in top developments in other UK cities. The increase in London’s international profile has generated a rivalry between provincial cities, whilst a demographic shift to these cities has led to an increased demand for smaller units in high density schemes – hence the resurgence of the tall residential building across the UK. The high rise residential tower is now widely recognised as a rapidly developing sector (EC Harris & Knight Frank LLP, 2004).

This type of residential developments, which include high and medium density residential and regeneration apartment buildings, have been largely forward funded by the creation of the buy-to-let market in the UK. These developments require a significant amount of advanced funding for the necessary infrastructure, sub, superstructures, cladding, services and fit out costs involved. The viability of these cash intensive schemes has been improved by off-the-plan sales to buy-to-let investors, providing evidence of demand to banks and financiers funding the project.
This market has become the biggest investment market in the UK generating an estimated £130 billion investment into the private rented sector and £30 billion in ancillary services to the annual Gross Domestic Product (Savills Research, 2007). This investment market was given a kick start by the Government in the form of the 1988 Housing Act, giving Landlords the ability to charge market rates and regain possession of their properties via the Assured Shorthold Tenancy Agreement. The dramatic market expansion that followed increased again in the late 1990’s following the introduction of buy-to-let mortgages, which was at a time when the UK house price was rising by an average of 10% per annum. This relatively new area of residential growth has been ‘pulled’ by the general confidence in the residential sector and ‘pushed’ by the volatility and weak performance of equities and other investment sectors since 2000 (average house prices have doubled since 2000, resulting in increased confidence and exceptional profit growth) (Savills Research 2007).

High density residential competition in other cities in the UK has intensified as a result of London’s successes and developers are seeing the need to differentiate their product from others – building tall is an obvious way of attracting attention as well as potentially increasing revenue. Signpost projects of this nature have recently been completed in Birmingham, Leeds and Manchester, Glasgow and Liverpool, as each competes for the title of the ‘UK’s Second City’ (Cityoffices.net, 2006)

Growth forecasts for in the UK residential market look positive, with Savills forecasting an average of 7% for the UK in 2007, whilst the South East and London market will see up to 20%. They state that the housing market is not overheated and there is no speculation-created ‘residential bubble’ to burst. This is backed up by the EC Harris Residential Research, forecasting a UK average of 6% for 2007. Both predict a slower growth toward 2010, but caveat this with the now standard concerns of global energy crisis and any ‘spectacular’ external market influences, offset by the net population growth through influx of immigrants and growing disposable income trends. These experts believe the UK population has one of worlds the strongest desires to invest in property.

The Potential Downside of Tall

Countering these positive predictions with a pessimistic tall building forecast, it could be argued that the Skyscraper Index will come into effect in London following this ‘tall building boom’ overlaid with the current financial market buoyancy. The author of this renowned index, Andrew Lawrence, demonstrated that historically, increase in tall building construction follows the peak of a country’s economic cycle and will be followed by significant economic slump (Thornton 2005). This is index is unlikely to effectively predict the UK tall building market, however, as it was an American study based on American economic cycles and even though it’s logic stood for the historic cycles, it unsuccessfully predicted the last two slumps (the last of which was 9/11 driven), mainly due to changing investment criteria and expectations since the index was created in 1999.

Hardening stance of the Main Contractor

In response to the high level of construction activity rising toward the end of 2006, main contractors are seen to becoming more selective on complex or high risk projects such as tall buildings. In February 2007, Davis
Langdon reported shorter main contractor shortlists and difficulties in attracting a selection of meaningful
tenders for these project types above the £50m net trade cost figure, resulting in a number of projects being
secured at premium prices. (Fordham, 2007). Clients of these project types are now increasingly using two stage
tenders, often with a negotiated second stage to make them more attractive to main contractors. This recent
hardening of negotiating position and higher price for the main contractor is due to:

- Recent consolidation of the London major project contracting market with Multiplex’s withdrawal and,
  others announcing concentration on alternative market areas;
- A buoyant construction market, with main contractors and specialist trade contractors at, or near full
capacity;
- Rising material costs for structural frames and cladding (Fordham 2007);
- Very limited number of specialist cladding contractors with the ability to undertake complex schemes;
- Limited availability of good design and management resources available in the marketplace;
- Client focus on large, complex mixed use projects demanding high levels of skilled management input;
- Clients increasingly risk-averse stance;
- Clients chasing planning consent in the City utilising signature architects to satisfy CABE and Mayor’s
  Office;
- Main contractor supply chain initiatives with specialist contractors have increased barriers to entry and
  have set up secured turnover, hence less diversity and competition;
- Main contractor’s increased use of single point negotiating with specialist trade contractors reducing
  competition;
- Main contractor’s hardening commercial position on the pricing of risk, profit, and higher preliminary
  and overhead costs, following widespread profit write-downs over the last year.

These changes in the market give a positive outlook to the top ten tall building contractors for the forthcoming
£50m-plus projects (Bovis Lend Lease are currently ranked either one or two in the commercial market, but not
ranked in the top ten for residential, the fourth tall building market driver). Rank tables and a graphic illustration
of market position are included in the following section of this report, Figures 4, 5, 6 and 7.

The Fragmented Tall Building Construction Market and BLL’s Place Within it

The UK construction market is seen as very fragmented in comparison to other UK industries (THF, 2001). The
majority of construction companies, irrespective of size, operate as management contractors employing little
direct labour and pass on the site based work to a wide variety of sub-contractors, sub-sub-contractors and self-
employed labour (Construction Task Force, 1998). Investment in fixed assets tends to be very low, with the
exception of land banks for some builder/developers. Both Egan (as chair of Rethinking Construction) in
Accelerating Change and Latham in Trust and Money and Constructing the Team state, very few contractors
have meaningfully addressed the supply chain with formalised management and committed volume (Latham, 1993).

The resulting highly elastic, low cost delivery system that makes no demand on risk capital is the free market response to decades of wildly fluctuating demand over time and geographical location and to the obsessive focus on first cost as opposed to running cost, reliability, quality and other manufacturing industry mantras. The better organised medium / large building companies are close to the ideal ‘virtual company’, employing few construction workers of their own, operating in numerous locations which change quickly in response to economic forces and returning ‘double digit’ profit over the last ten years. Bovis Lend Lease is different to the industry standard model as it employs in excess of seven thousand management staff worldwide (though few construction workers) and holds a Facilities Management and Real Estate Investment and Development arm. It does strive to maintain flexibility and quick reaction times to changes in market demand by sector and geography. A good phrase coined in the BLL Sydney Office in 2000, shows what the company strives to achieve - ‘local building knowledge on an international scale’.

BLL’s Competitors

Bovis lend Lease’s closest market sector competitors are currently Skanska, Lang O’Rourke Group, Sir Robert McAlpine, Mace, ISG and Canary Wharf Contractors. This list previously included Multiplex, but the November 2006 announcement of a withdrawal from competitive tender work has potentially eliminated them. Investment in capital is higher in some of Bovis Lend Lease’s tall building competitors:

- **Laing O’Rourke** investment in Select Plant Hire, Expanded Ltd. Crown House Technologies and Off Site Manufacturing allows for potential provision of some specialist services required for tall building at cost, to assist the winning of work.

- **Skanska’s** specialist businesses of Cementation Foundations, Richard Lees Steel Decking, Clarke & Fenn Drylining, Rashleigh Weatherfoil ME&P Services lend in-house specialist support to the fundamental function of winning complex project work. This strategy worked well to win and deliver 30 St Mary’s Axe, where Skanska utilised seven of their UK Operating Units to deliver the project on programme and budget. This high profile success has placed them in good stead for winning future tall building work.

- **Mace** has invested in internal specialist service providers, as opposed to delivery providers. The most successful of which in respect to winning large projects is Senses, the in house cost consultancy service. They provide strategic cost advice, feasibility studies, development appraisals, landlord-tenant negotiations, land and premises search, procurement and contractual advisory services, affording them an early involvement in tall building project teams.

- **Carillion** utilised their ‘whole project approach’ utilising in house specialist services to successfully deliver Beetham Tower in Manchester. This has directly resulted in the award of two further Beetham tall buildings.
These competitor strategies should be reviewed in more detail to assist in the formulation of the Bovis Lend Lease tall building strategy moving forward.

Bovis Lend Lease’s Position

This research shows the London office sector forms the largest subset of the tall building market (54%) and is the largest source of available data in the industry. Therefore, Bovis Lend Lease’s position has been analysed and catalogued by four categories over the last eight years to determine the true position and forecast trend. The four categories are:

- London office buildings complete since 1999;
- London office buildings complete since 2005;
- London office buildings in the 2007 pipeline;
- London office contract values from Jan 06 – Jan 07.

These independent research results graphically shown in Figures 4-7, clearly indicate BLL as the consistent market leader in the London office sector, being top contractor for new offices by area built since 1999, holding this lead through to 2005 and is forecast to continue this lead into the projected pipeline work for 2007 (provided it wins a share of the unallocated 30% of new offices for 2007). This data is backed up by the recent Construction News Contracts League, placing Bovis Lend Lease as the top commercial contractors, by value for 2006-07.

**Figure 4.**

Key Market Players, Contractors, Offices, London. ‘All Buildings since 1999’ March 2007 (Cityoffices)
Figure 5. Key Market Players, Contractors, Offices, London. ‘All Buildings Under Construction or Completed Since 2005’ March 2007 (Cityoffices)

Figure 6. Key Market Players, Contractors, Offices, London. ‘All Buildings Potentially in Pipeline’ March 2007 (Cityoffices)
The research undertaken for this report shows the London office market is the largest subset of the London tall building sector making up 54%, the other subsets are residential at 28% and mixed use tall buildings at 18%.

In this tall office building sector, the construction leaders are currently perceived to be Carillion, Mace, Laing O’Rourke Group, Skanska, Canary Wharf Contractors and BLL, although no journal, professional body or market researcher could be sourced who charts progress particular to this sector. This data has been compiled from the list of tall buildings generated by this research.

It can be argued from the preceding charts and from an analysis undertaken of the number of tall buildings (greater than twenty stories) as a percentage of current commercial opportunities that Bovis Lend Lease are chasing, then Bovis Lend Lease are one of the top three Contractors for commercial tall buildings. As previously clarified, no professional body holds information on construction companies specific to tall buildings, so this has to be determined from first principles from the collated data that follows.

**Current Commercial Office bids that Bovis Lend Lease are converting to projects**

There are sixteen office projects, 20% of which by number are tall buildings. (Furey, P. BLL Cost Planning, 06.03.07):

- **190 Strand** Under 20 storeys. BLL appointed for Stage 2 of 2 Stage competitive tender
- **N°1 New Change** Under 20 storeys. BLL negotiating CM appointment with Client
- **20 Fenchurch Street** **Over 20 storeys.** BLL negotiating appointment, subject to Public Hearing and approvals
- **122 Leadenhall Street** **Over 20 storeys.** BLL working under a pre-construction appointment and are negotiating full CM appointment
Regent’s Place Under 20 storeys. Ditto as last
One Southampton Row Under 20 storeys. BLL appointed under a negotiated GMP arrangement, team are now firming up the lump sum
New Bond Street Under 20 storeys. BLL just appointed to build two new buildings
Central St Giles Under 20 storeys. BLL won a competitive ‘capability’ submission
64-74 Mark Lane Under 20 storeys. BLL negotiating a GMP
200 Aldersgate Street Refurbishment over 20 storeys. BLL submitted 2nd Stage lump sum offer, under review
BP Sunbury Blocks E&J Under 20 storeys. LL acting as PM
Plot 106 Spinningfields Under 20 storeys. BLL finalising lump sum prior to commencement of works
Chiswick Park 8&9 Under 20 storeys. BLL preparing lump sum/GMP proposal
Sony BMG Refurbishment under 20 storeys. BLL awaiting appointment for second stage following competitive two-stage tender
Semple Street Under 20 storeys. BLL Scotland just appointed to the second stage following competitive two-stage tender
Salford Media Centre Under 20 storeys. BLL assisting in development of new facility and are continuing to negotiate our appointment

Similarly for residential:

Newington Butts 44 storeys. BLL working on preconstruction agreement
Bridgewater Place 32 storeys. BLL due for completion Q1 2007
Adelaide Wharf Under 20 Storeys. BLL due for completion Q2 2007
KX200 Under 20 Storeys. BLL due for completion Q3 2007

This indicates a high proportion of tall building work in the residential sector, compared to the size of the sector.

This raises the question of how Bovis Lend Lease should maximise this marketable skill to create further opportunities, which should be investigated further in formulation of a tall building sector strategy.

Current UK Tall Building Project List

This section of research was undertaken to determine the size of the current tall building market in the UK, the type of tall building and the organisations involved in these projects. It includes those tall buildings feasibly reaching site in the next three to five years and excludes ‘visionary’ tall buildings with a low likelihood of being built. This research commenced with a literature review of industrial publications including Construction News, Building Magazine, New Civil Engineer, Structural Engineer, Estates Gazette, AJ, RIBA Journal, British Council of Offices and Property & Real Estate. The information gleaned was deemed inconclusive and so was supplemented by visits to live projects in London, contacting previous BLL Client organisations, generating a list of tall buildings from delegates at the 2006 Taylor & Francis Talking Tall, 2nd Annual Conference and
accessing numerous tall building property knowledge databases such as cityoffices.net, skyscrapernews.com and emporisbuildings.com to determine the complete market picture. It has been broken down geographically into London, the South East and the Balance of the UK and then sorted to determine the demand for Commercial, Residential and Mixed Use in each area, shown graphically in Figure 8:

![Demand For Tall Buildings](image)

**Figure 8. Demand for Tall Buildings in the UK.**

**London**


**201 Broadgate Tower.** Team: BLL, Arup. Frame: steel 5 storey megaframe & conc. on Hollorib. Height: 161m, 34 storeys. Status: under construction, frame at level 21, completion 2008. Approx Consn Cost: £100m


**1-10 Blackfriars Road.** Team: Unknown. Frame: steel & conc on Hollorib. Height: 200m, 68 storeys Status: Outline planning approval, complete tbc. Approx Consn Cost TBC

**Vauxhall Tower.** Team: Arup Broadway Malyan. Frame: Insitu Concrete. Height: 180m, 49 storeys. Status: Concept Design, awaiting planning approval. Approx Consn Cost TBC

**Columbus Tower.** Team: WSP. Frame: steel & conc on Hollorib. Height: 239m, 63 storeys. Status: Awaiting planning approval, complete 2009. Approx Consn Cost TBC

**Willis Building (51 Lime St).** Team: Mace, Whitby Bird. Frame: Steel & conc on Hollorib. Height: 125m, 29 storeys. Status: under construction, complete mid 2007. Approx Consn Cost: TBC

**Newington Butts.** Team: BLL, AKT, Richard Rogers. Frame: insitu conc, slip core & post tensioned slabs. Height: 140m, 44 storeys. Status: Detailed Design, awaiting planning approval, start mid 2007, complete 2009 Approx Consn Cost: £45m NTC

**Citygate Eco Tower.** Team: M3 Architects. Frame: TBC. Height: 485m, 108 storeys. Status: Concept design Approx Constn Cost: TBC

**Heron Tower.** Team: Skanska, Arup. Frame: TBC. Height: 202m, 41 storeys. Status: Planning permission granted Jan 06 (1 week steel floor cycle planned – Severfield). Approx Constn Cost: TBC


**Bishopsgate (was DIFA) Tower.** Team: Arup, Kohn Pedersen Fox. Frame: TBC. Height: 300m, 63 storeys, 88,257 sq m of office space. Status: Planning approved Oct 06. Approx Constn Cost: TBC

**100 Bishopsgate, EC2.** Team Great Portland Estates, Allies and Morrison Architects. Frame: Concrete core and steel frame. Height 165m, 40 storeys. Status Proposed early 2006, existing tenancy agreement on site may delay start till 2012. Approx Constn Cost: TBC


**1 Millharbour.** Team: WSP. Frame: TBC. Height: 140m, 50 storeys. Status: Under construction, complete 2009 Approx Constn Cost: TBC

**Doon Street Towers.** Team: Arup. Frame: TBC. Height: 168m, 48 storeys. Status: Outline planning ongoing, complete 2010. Approx Constn Cost: TBC


**London Bridge Tower (Shard).** Team: Mace, WSP, Arup. Frame: Low - steel megaframe & conc shaft, Mid – Conc slab and core, Top – steel outrigger. Height: 310m, 83 storeys. Status: Construction started 06, completion due 2012. Approx Constn Cost: £350m


**Heron Quays West Towers.** Team: WSP. Frame: TBC. Height: 139m, 47 storeys. Status: Under construction, complete 2009. Approx Constn Cost: TBC

**20 Fenchurch Street, EC3.** Team: Land Securities PLC, BLL, Rafael Vinoly. Frame: Reduced from 45 to 36 storeys. Height: 160m. Status: Planning approved, called in by Secretary of State Dec 06 Approx Constn Cost:

**Tate Tower, Hopton Street.** Team: TBC. Frame: TBC. Height: 54m, 20 storeys (previously 32). Status: Yet to be built. Approx Constn Cost: TBC

**Park Plaza Hotel, Westminster Bridge.** Team: TBC. Frame: TBC. Height: 70m, 28 storeys. Status: Planning approval. Approx Constn Cost: TBC

Vauxhall Cross, Lambeth SW8. Team: Developer London Regional, Squire & Partners, Frame: TBC Height: 180m, 49 storeys. Status: Concept Design, awaiting planning approval, planned to complete 2009 Approx Constn Cost: TBC


Blackwall Tower, London Borough of Tower Hamlets. Team: Swan Housing Group, BLDA. Height: 74m, 24 storeys. Frame: TBC. Approx Constn Cost: TBC

City Pride Tower, off Heron Quays West, Docklands. Team: Developer The Oracle Group, Galliard Homes. Frame: TBC. Height: circa 105m, 40 storeys. Approx Constn Cost: TBC


Victoria Towers, Bresenden Place, Victoria Street Station. Team: Land Securities, KPF Architects. Frame: TBC. Height: 3 tall buildings of 100m. Approx Constn Cost: TBC


Wellesley Square, Croydon. Team: Berkeley Homes, Rolfe Judd. Frame: TBC. Height: 120m, 43 storeys. Plans for the residential tower were unveiled at MIPIM, March 07.

St Katherine's Point, St Katherine’s Dock. Team: Developer Reit Asset Management, Sturgis Associates Architects. Frame: TBC. Height:17 storeys, 55m.


Other Cities in the South East


Station Road Tower, Reading. Team Kier Properties, Scott Brownrigg. Height: 105m, 40 storeys. Status: Submitted for planning approval Feb 07

Other UK Cities Outside the South East


The Plaza, Phase 2, Leeds. Team: Developer Unite, Architect Carey Jones. Frame: TBC. Height: 36 storey, 108m. Status: Phase 2 the tower over the Plaza was approved by Leeds City Council Feb 2007


The Arc, Titanic Quarter, Belfast. Team: TBC. Frame: TBC. Height: three towers circa 70m tall and numerous mid-rise buildings. Status: Outline planning approved for Phase 2 for 298,300 m2 of space and 21 buildings to be built over the next 15 years


Chesham House, Sheffield. Team: Developers RREEF (UK) Ltd. Architects John McAslan and Partners. Frame: TBC. Height: 24 floors, 70m. Status: Outline planning submitted 2007 for 10,000 square metres of retail space, 5,000 sq m offices, 19,000 sq m of residential featuring 210 apartments.


Canopus Twin Towers, Salford. Team: Developer BSC, Arca Architects. Frame: TBC. Height: 46 and 31 floors respectively, tallest is 164 m, lower is 108m. Status: Planning application lodged Feb 2006 with Salford City Council. 50,000 square metres of commercial space.

Estimate of Current UK Tall Building Market Value

To determine the value of the current tall building market, construction net trade cost (NTC) has been extrapolated from the limited accurate cost information available. No definitive or reliable construction cost information can be found for the majority of projects at design stage, or those in a later stage with competitor construction companies. Therefore, Bovis Lend Lease project costs have been utilised from the 122 Leadenhall, 201 Bishopsgate, 125 Old Broad St, 20 Fenchurch St. and Newington Butts cost plans. This has been supplemented by a published construction cost projection for The Shard. These six selected tall building projects are a representative cross section of the current UK tall building market, from small footprint residential, to existing tall building reclad/refurb, to cutting edge speculative commercial, to London’s leading mixed use scheme. They are deemed therefore give a representative UK tall building ‘average’ construction cost.

Using the average of these construction NTC per m height above ground (as storey heights vary depending on commercial or residential use), a calculation of the total value of the UK tall building construction market can be made:

\[
\text{(NTC)=Net Trade Cost)}
\]

122 Leadenhall NTC £253m / 222m height = £1.14m/m
201 Bishopsgate NTC £181m / 161m height = £1.12m/m
125 Old Broad St NTC £80m / 100m height = £0.80m/m
20 Fenchurch St NTC £257m / 160m height = £1.60m/m
Newington Butts NTC £55m / 140m height = £0.39m/m
The Shard NTC £350m / 310m height = £1.13m/m

Average construction (NTC) cost per m height = £1.03m/m height
Therefore,

Total cost of construction for **London and the South East** projects listed above

= cumulative height of tall buildings x average NTC / m height

= (6968m London +422m South East) x £1,030,000/m

= £7,611,700,000

A conservative estimate of the potential BLL market share can now be made assuming 10% success rate on pursuing 50% of the London & SE projects listed above, i.e. the win rate of work is taken 5% of total London & SE market, which equates to winning just over 2 of the total 47 projects proposed in this region.

= £380,585,000

To determine the potential construction value per year, we need to determine the average gestation period of a UK tall building (which has been calculated in this research as 8 years in total made up of 5 years design development and preconstruction, plus 3 years construction).

It is unknown when any building will progress from planning into construction phase and generate potential income if won by BLL, so assume an equal spread over the average gestation period of 8 years.

Therefore, annual potential turnover for BLL winning 5% of tall building in London & SE is:

= £380,585,000 / 8

= **£47,573,000 per annum**

Using the same method of calculation, the total value of **tall buildings in the balance of the UK**

= 2277m x £1,030,000/m = **£2,345,300000**

Therefore, annual potential turnover for BLL winning 5% of tall building in the balance of the UK is:

= £117,266,000 / 8

= **£ 14,658,000 per annum**

In summary, the total annual potential turnover for the BLL winning a conservative 5% of all tall building projects across the UK is:

= **£62,231,000 per annum**

Mixed Use Comes of Age
The third emerging tall building market referred to earlier in this report is that of the mixed use tall building. Design for mixed use tall buildings as opposed to single occupancy presents complex problems and opportunities. This form is increasing in popularity worldwide, as well as in the UK. There are a number of issues specific to this form of tall building that need careful consideration to ensure success:

- Optimisation of floor plate design to suit different requirements for floor space depth and riser configurations, using either a stepped floor plate or tapered building profile;
- Use of efficient transfer structures to accommodate changes in the structural grid;
- Stacking of the tower efficiently to optimise use of differing floor plate sizes and minimise lifting requirements by locating lighter lift demand occupiers toward the top (residential and hotel users) thereby reducing car numbers and core size;
- Maximising the efficiency of means of escape by phase evacuation, fire escape lifts, efficient core and stair layouts and accommodating increased security and privacy issues of multiple occupiers;
- Provision of dedicated services to each occupancy group and isolating each group for fire, security and acoustics;
- Allowing heating and cooling load transfers between occupier groups to maximise energy efficiencies.

A successful example of a mixed use tall building is New York’s recently completed $1.7 billion, 2.1 million sq ft Time Warner Center, which is acknowledged to currently lead the way for occupier diversity. Behind its glazed façade there is a four-level shopping centre over a basement supermarket and health club. Two offices sit on top the mall, one devoted to Time Warner, including studios for CNN and one tenanted. A residential tower rises above the restaurant, bar and retail area to the South. The North tower includes a 251-room hotel and more private apartments.

The biggest and earliest advantage for the developer Related Companies, was that the various uses balanced the financial risks and delivered an early income stream in the form of off-the-plan sales of residential.

Time Warner Center used a different structural and mechanical solution for each occupier group. The most efficient system was to transfer the high loads from the concrete frame and shear wall structure for the hotel and residential levels through gigantic trusses to a steel-framed office grid below. The long spans in the shopping concourse below this fell outside the higher bulk of the building requiring further transfer structures. Additionally each occupier group had to have its own lobby presence requiring seven lobbies at street level. Sky lobbies would have been more space efficient, but tenants and owners who pay these rates do not want to transfer. One hundred-thirty elevators serve the building.

The UK leading example of a mixed use tall building is still at design stage, in the form of Renzo Piano’s London Bridge Tower. This stacks narrow spire of private apartments above a hotel over a thickening base for offices and retail, all over the refurbished railway station. The functions meet at dramatic sky lobbies, visible from outside. The specific construction related issues in building mixed use tall buildings will be examined further in this research.
Costing of Tall Buildings

The cost and scarcity of developable land, the permitted footprint, building bulk and height, quality of specification and the time required for design, construction and occupation are all key cost drivers of tall buildings. The medieval street pattern of the City of London creates small, complex footprints. The proximity of listed buildings and conservation areas influences the articulation of tall buildings. Both factors serve to produce structures of relatively high cost (Watts, 2005).

Tall buildings have a longer lifespan than low rise equivalents, due to the high level of first cost and high level of removal costs, favouring their retention. Modern tall buildings are planned for a much longer lifespan, with higher initial investment in their design and capital cost being offset over the long life cycle of the building.

The main opportunities of tall building design and construction are the exploitation of standardisation, modularisation and repetition across major cost elements along with the overlapping of the construction activities. Achieving and maintaining speed is crucial to successful project delivery. Procurement strategies that allow the overlapping of design, procurement and construction are essential to success.

EC Harris developed a model in 2004 which plots construction cost against height for residential towers. They examined 7 projects and plotted construction cost against height. This shows cost increases with height, but levels off at 50 storeys. The major rise in costs is between the 20th and 40th floor due to the increased complexity of building at height, which then achieve economies of scale above 40 floors. This also shows the cost premium for complex shape and design. To achieve planning consent and good sales, a residential tower design needs to be attractive, but not necessarily cutting-edge. They indicate a large percentage of construction costs for mechanical (comfort cooling and extract) and electrical systems (structured wiring, network, audio and security technology). Additionally, high costs are allocated to provision of main and ensuite bathrooms, kitchens (EC Harris & Knight Frank LLP, 2004).

Tall buildings are intrinsically less efficient and more expensive than low riser schemes due to lower Net to Gross ratios because of the space required for risers and cores. Additionally, the efficiency of cladding the tower is low due to the low wall to floor ratio (small plan area). Structural design is a key driver of construction cost. (Morrell, 2006). Every aspect of the tall building should be optimised for material content, cost and time.

The key engineering and cost issues include:

- **Slenderness Ratio** – Slenderness ratio is the relationship between height and plan width. Conventional ratios are 1:8 optimum and 1:12 maximum. Wind has a bigger effect on slender tall buildings and can set up forces which needs additional structural mass or dampers to counteract.
- **Building Orientation** – Wind load will vary depending on orientation to the prevailing wind. Correct building profile orientation can reduce wind load and therefore cost.
- **Swaying and Damping** – wind induced motion can be felt by occupants. Wind tunnel testing should guide the design to reduce effect. Costly structural damping can be introduced. Concrete’s mass assists
in resisting the sway more efficiently than steel. Additional active damping may be required at great cost.

- **Stability and Robustness** – Tall buildings generally resist lateral loads through their core. The more slender the tower, the greater need to utilise the full depth of the building by having additional structure at the perimeter – outriggers, mega-bracing and bundled tubes increase the bending stiffness of the building. Robustness, or collapse resistance has been an area of great focus since 9/11 to ensure a direct and efficient load path to the foundations.

- **Structural Grid and Floor Structure** – structural grid requirements affects the frame and foundation systems available. Floor structural depth will effect space available for service zones and flexibility of space for different users and provide the minimum economical storey height. The saving of 100mm per floor on a 40 storey building could give an extra floor and therefore, revenue. The balance between structural repetition and variety can have large time and cost consequences.

- **Thermal Mass** - heating and cooling are relatively constant for a residential tower so concrete slabs will act as a thermal store. Cheaper night time power can be used for heating and cooling. Concrete also provides acoustic damping.

- **Façade Treatment** – Cladding on a tall building must be of high specification and detailing to accommodate the relatively large movements each elevation experiences due to differential loadings from solar gain, wind and rain. Developers invariably demand large areas of glass to maximise views and hence income. Higher glass performance is necessary as glass area increases to allow Part L requirements to be met. Interstitial blinds or external shading are commonly required on the Southern elevation (UK) to offset solar gain. Active vented facades are more expensive but can be offset by lower running cost. The more slender the building, the lower the wall to floor ratio, the higher the proportional cost of cladding. External envelope costs are a quarter of the total project cost of a high rise scheme (Watts, 2006).

- **Steel V’s Concrete Frame** – numerous advantages and disadvantages of both. The decision will be driven by the most efficient frame solution for the site, specialist contractor availability and cost.

- **Internal Fit Out** – The high level of finishes specification for a tall building lead to high cost of fit out. In tall residential schemes of high density and specification, the cost of £9000 - £12000 per bathroom and £15000 - £40000 per kitchen. Bathroom pods may cost more, but offer higher quality control and reduced fit out time if the layouts are repetitive. Accommodation of large tolerances and movement associated with tall buildings in finishes is expensive, It may be cheaper to tighten tolerances by stiffening the structure.

- **M&E Installations** – building over 100m in height increases M&E costs disproportionately. This can be mitigated by careful services engineering:

  - Heating and cooling systems above 100m need to cope with higher pressures adding 30% to cost; fully ventilated schemes are expensive due to the size of ducting required, reducing net floor area. Intermediate plant floors may be beneficial above 100m, but take floor area and mechanical ducting will penetrate the facade; Dry risers can protect schemes up to 60m in height, above this sprinklers are reqd at a cost of £25/m2; Lift installation cost increases with height and demand volume. It is cheaper and less
demand on floor space to increase speed of lifts rather than number, however, high speed lifts have a high cost premium and long lead times. Fire-fighting provision must be made over 18m in height. Lifts typically add 3% to construction costs (EC Harris 2004).

- Logistics – tall buildings are generally constructed on constricted inner-city sites, especially true in London. This may result in inefficiencies through delivery, storage, handling, and delivery to the work face via hook or hoist. Trade contractors have been shown historically to add a premium to cover their expected risk of inefficiencies. This is difficult to price and can be substantial percentage of cost. Productivity is affected by the risk of winding off delaying deliveries and installation as well as the extended travel time for workforce to workface. This may be partially offset by the ability to work on many levels simultaneously, but depends on the ability of the main contractor to plan, coordinate and avoid the typical labour peaks and troughs. Welfare facilities at regular intervals up the building reduce lost time of labour in hoists. Frame cycle times are fundamental to programme as is achieving a watertight building, both on the critical path allowing dry finishing trades to commence. Correctly sized and located craneage is mandatory to provide sufficient hook time for dependant trades. Long procurement times for specialist tall building elements lead to high inflationary costs, especially relevant as the artificial Olympic deadline looms. As a result, preliminary costs will be higher for a tall building. This is supplemented by the increased health and safety requirements and higher risk of programme failure due to the high level of repetition and coordination.

- Phasing – With a residential tower there is a balance between early release to the market giving an early revenue return, not flooding the market and minimising construction costs. There is limited opportunity for phased release in a tall building as opposed to a horizontal residential development, but is vital for scheme viability. Early contractor involvement will allow investigation of horizontal and vertical phasing of a tower achieved through early scaffold free elevations, early commissioning, and segregation of lifts and staged commissioning of services. Phasing will increase construction cost as it will not be the most efficient work method, needing higher levels of management coordination, longer trade durations and enforced return visits.

- Main Contractor Preliminaries - The inherent cost and complexity of tall buildings will inevitably result in higher levels of staff, accommodation, plant and equipment for a longer duration. Investment in the main contractors’ preliminaries will mitigate pressures on trade contractors’ preliminaries, which can be substantially greater for tall buildings and will avoid potential duplication (Watts, 2005). Additionally, design and construction contingency sums are much greater for tall buildings when indexed against lower buildings.

- Height equals Price – the residential market established a premium for higher level properties, to the extent that not only penthouses but sub-penthouses command a specialist market. Basement properties are discounted as they offer no outlook, ground floor are at a higher risk of being broken into, upper floors command good light and views. This gives a clearly established relationship between floor height and price. This is blurred on tall buildings as the floor difference becomes less distinct. The lowest floors have a negative price impact with rapid price growth occurring above these floors. This increase then
levels out over the mid-section of the tall building, with a huge growth for the top third floors. This pattern is dependent on the condition and strength of the market (EC Harris, 2004).

- Specialist Market, Small Pool – There are a limited number of main contractors interested in tall buildings in the UK, limited further by relevant experience and availability. The limited pool of high rise main contractor and trades reduces competition and therefore raises price. Early contractor involvement through partnering can give greater periods to review the design to ensure buildability. Additionally, once established, partnering will allow repetitive design and standardisation across the supply chain. Economies may be made from modularisation and prefabrication. It is acknowledged that trade contractors price a higher level of risk in tall buildings due to lack of experience and their bespoke nature. Better contractor knowledge through early involvement should lead to a lowering of these risk premiums.

Tall Building Revenue Generators

To offset the high cost of building tall there are greater revenues generated. Irrespective of floor plates, landmark status, form and proportion, development costs per m2 of gross floor area increase with height. To be viable the value of tall buildings per m2 must also be higher and market evidence suggests it is possible for tall buildings to provide an acceptable long-term return. The macro and micro economics for a tall building will vary according to location. London is a ‘young market for tall buildings’ and as increased knowledge and experience is gained, cost and efficiency premiums may reduce (Watts 2005).

Knight Frank believes the revenue premium for tall buildings is due to:

- The scale of the development adding amenity value in the form of exclusive shops, restaurants, bars and hotels;

- The brand awareness – Beetham brand has been established though their internal marketing of both towers;

- The height of the profile - landmark developments infer high quality build, fittings and fixtures.

- The rarity value attached to these developments. This factor may reduce as the supply of tall buildings increase.

A case study was conducted of 3 residential tall buildings; the £150m development Beetham Tower, Deansgate, Manchester which showed it achieved an 18-23% price premium over the standard new build market. Beetham Tower, Old Hall St in Liverpool showed an increase of 15%. Crosby Homes 1 Deansgate, Manchester was seen to have led the market on high density tall residential and achieved an 8-10% premium, but was only 14 stories. (Knight Frank Residential Research 2004).
However, the financials of building very tall are brought into focus by an American study (EC Harris 2002) which plots the construction cost and whole life cycle cost per occupant of a number of tall buildings of varying heights. The results indicate the best return on investment is given by 20 storey buildings.

APPENDIX


Key Market Players, Contractors, Offices, London. ‘All Buildings since 1999’ March 2007 (Cityoffices)

<table>
<thead>
<tr>
<th>Main Contractors</th>
<th>Projects</th>
<th>Total m²</th>
<th>Total ft²</th>
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Key Market Players, Contractors, Offices, London. ‘All Buildings Under Construction or Completed Since 2005’ March 2007 (Cityoffices)

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Key Market Players, Contractors, Offices, London. ‘All Buildings Potentially in Pipeline’ March 2007 (Cityoffices)

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Construction News Contracts League, Commercial Contractors (ex-Retail) Jan 2006 – Jan 2007 (15.02.07)

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APPENDIX E  BUSINESS CASE FOR THE LIFTING WING
University of Surrey

School of Management

MSc Entrepreneurship and Creativity

Assignment Two

Name of CICE EngD Student: Ian Skelton        I.D No: 6046980

Title of MSc Project: Business Plan for the Think Tall Company

Name of Module Contributor: Dr Spinder Dhaliwal

Submitted: 14th November 2007 via email

Word count: 3004 (main text body)
Executive Summary

The Think Tall Company is concerned with developing innovative construction techniques allowing more efficient building of tall buildings. It has at concept stage a number of innovative tools that will reduce the build period tall buildings by eliminating or reducing construction time, cost and safety risks. The company is run by Ian Skelton, a qualified Civil Engineer, Master of Project Management and shortly to be, Doctor of Engineering. Ian has worked as a main contractor on tall buildings both in the UK and Australia and so has a detailed understanding of the polarised needs of time, cost, quality and safety on such projects. The Think Tall Company Tools are designed to satisfy these diametrically opposed needs.

The first such tool to be ready for the market is the Lifting-Wing. It is a 6.5m long x 3.5m wide by 2.5m high aerodynamic wing-on-end, built of a light weight, high impact resistant clear plastic skin over a frame. The Wing is connected to the crane hook and is lowered over the bulky construction material to be lifted and propped off the load, fixing its position. The Wing fully encapsulates the load suspended from the hook of a tower crane, thereby giving the load a predictable and more controllable wind profile, allowing safe lifting in higher and gustier wind-speeds. This will reduce the industry accepted norm of 40% down time for the tower crane, saving time on the critical path of the tall building construction programme and hence, substantial costs.

The intellectual property of this and the next concept tool to be market ready, the Mag-Spanner, are currently protected by International Online Copyright Registration and are about to be internationally patented.

The UK tall building market sector is forecast over the next 3-5 years to be circa £10billion Net Trade Cost. Growth is forecast conservatively as 5% annually, boosted by the recent glut of tall building planning permissions approved in London and other cities and topped by the proposed Olympic residential towers. The market opportunity that this company addresses is the current boom in demand for UK tall buildings, directly comparable in size to the skyscraper boom of Manhattan Island in the 1920’s. Every tall building construction company must be seen to build the highest quality, in the fastest and safest manner to win these prestige projects. The innovative tools produced by the Think Tall Company will be in demand from every one of these specialist construction companies.

The central competitive advantage of this company and its innovative products is that no-one else is in this specialist arena. Even on an international scale, no-one is producing specialist products of this type as they fall between traditional client demands in the construction industry: Tower crane suppliers and major plant companies have no interest in increasing construction speed (therefore reducing equipment hire time and revenues), whilst trade contractors similarly have little interest in committing to tighter programmes than the ‘norm’, with the tower crane being their Get-Out-Of-Jail Card, as its time and cost risk are traditionally the main contractors. Main contractors themselves are not interested in producing niche products to reduce
time and cost risk as it is deemed outside their core business. This is where the Think Tall Company comes in.

Traditionally, if tower cranes are winded off, this may cause an extension to the tall building programme, resulting in either the tall building client paying increased preliminary costs (Construction Management contract), or the Main Contractor loosing profit (Lump Sum Contract). The niche products of The Think Tall Company capitalise on this unexplored market opportunity and once proven and utilised by one of the industry players (traditionally slow to accept innovation and change), they will be demanded by every building company to retain their competitive edge. They will become vitally important to two very wealthy customers – the tall building client and main contractor.

The objectives of the company in the short term are:

1. Commission a scale model of the Lifting Wing and full scale Mag-Spanner
2. Wind test the Lifting Wing scale model. Determine increased levels of wind speed safety serviceable against current ‘norm’ windspeed
3. Calculate typical tall building programme saving and hence value of prelim cost saving, ignoring the value of performance clauses or Liquidated and Ascertained Damages clauses.
4. Secure International Patent
5. Furnish wind test report and obtain Lifting Wing reviews from key market players (BLL Safety Department, BRE, Tim Watson Consultants, CPA’s Tower Crane Interest Group, HSE)
7. Determine sale versus rental marketing strategy and establish agreements with plant hire companies, though crane suppliers or direct sales force.

Medium term objectives are to successfully establish the manufacture and sale the Lifting Wing, commence production of the Mag-Spanner and develop the next product. The key marketing strategy will be to develop sales leads through existing construction industry contacts.

Long Term objectives are the establishment of The Think Tall Company in the industry due to the existing products, the development of the future stream of products and investigation into the feasibility of a tall building consultancy service. A natural market growth to be targeted early is overseas, with the US, Asia Pac and UAE all undergoing tall building booms currently.

Evidence of success of the Company Director can be determined from the CV in Appendix 1. Evidence of success of the company will follow shortly as initial concept models are tested, reviewed by trade experts and working prototypes are tested on Bovis Lend Lease pilot projects.

It should be noted there is an ongoing early discussion with Bovis Lend Lease Ventures regarding the raising of capital to fund the development of the Lifting Wing.

The current finance requirements, stake in the company on offer and the proposed exit strategy for the investor are excluded from this assignment, but will be worked up separately.
Contents

Introduction to the Think Tall Company and its People
Products – the Think Tall Tools
The Market
Business Strategy
Marketing Plan
Sales and Distribution
Production Strategy
Provisional Costs / Revenue
Conclusion - Evaluation of the Exercise
References
Appendix
Introduction – the Think Tall Company and its People

The Think Tall Company is a new venture concerned with developing innovative construction techniques allowing more efficient building of tall buildings. It has at concept stage a number of innovative tools that will reduce the build period tall buildings by eliminating or reducing time and cost construction risks. The company is run by Ian Skelton, a qualified Civil Engineer, Master of Project Management and shortly to be, Doctor of Engineering. The ideas have resulted from the research into innovative tall building techniques Ian has undertaken for the Engineering Doctorate at Loughborough University and from his experience working for main contractors on tall buildings both in the UK and Australia. This detailed understanding of the polarised needs of time, cost, quality and safety on such projects has given rise to the Think Tall Company Tools, designed to satisfy these diametrically opposed needs.

Two tools are close to being ready for the market. These are the Lifting-Wing and the Mag-Spanner. Both products break new ground and offer something not currently available in the market place. They are described in detail in the next section.

Research shows the average UK tall building is circa £200million pounds (Net Trade Cost) and there are thirty nine tall buildings potentially starting on site in the UK in the next three years. This specialist market sector is forecast over the next 3-5 years to be circa £10billion (NTC). Growth is forecast conservatively as 5% annually, until 2012, when construction forecasts are uncertain due to the completion of the Olympics and potential downturn.

However history shows us that the construction industries in key foreign markets will boom whilst the UK is in potentially slowing down, ideal for the Think Tall Company’s medium term international expansion plans.

The market opportunity that this company addresses is the current boom in demand for UK tall buildings, directly comparable in size to the skyscraper boom of Manhattan Island in the 1920’s. Every tall building construction company worldwide must be seen to build the highest quality, in the fastest and safest manner to win these prestige projects. The innovative tools produced by the Think Tall Company will be in demand from every one of these specialist construction companies.

The central competitive advantage of this company and its innovative products is that no-one else is in this specialist arena. Even on an international scale, no-one is producing specialist products of this type as they fall between traditional client demands in the construction industry: Tower crane suppliers and major plant companies have no interest in increasing construction speed (therefore reducing equipment hire time and revenues), whilst trade contractors similarly have little interest in committing to tighter programmes than the ‘norm’, with the tower crane being their Get-Out-Of-Jail Card, as its time and cost risk are traditionally the main contractors. Main contractors themselves are not interested in producing niche products to reduce time and cost risk as it is deemed outside their core business.
This is where the Think Tall Company comes in. Traditionally, if tower cranes are winded off and cause an extension to the tall building programme, either the tall building client will pay increased preliminary costs (Construction Management contract), or the Main Contractor will lose profit (Lump Sum Contract). The niche products of The Think Tall Company capitalises on this unexplored market opportunity and once proven to and utilised by one of the industry players (traditionally slow to accept innovation and change), will be demanded by every building company to retain their competitive edge. They will become vitally important to two very wealthy customers – the tall building client and main contractor.

The current organisational structure is sole trader. There are currently no plans for increasing the people employed by the company as short term needs are better satisfied by outsourcing to independent specialists, for example the model making, wind testing, design adjustments, full scale mock-up production, seeking expert opinions, full scale tower crane trials etc.

Once this development stage has been successfully completed, specialist staff will be recruited to assist with production, sales and marketing.

Business advisors today include Bovis Lend Lease Ventures, Barclays Bank, and Waseem Malleck (MD of C&G Construction).

The existing alliance with Bovis Lend Lease Ventures is a potential source of future investment and business mentoring. Additionally, BLL has an established construction industry supply chain including several large plant hire companies that could be approached for a potential sale and marketing alliance.

Long Term objectives are the establishment of The Think Tall Company in the UK industry via the proven capability of these two products, the development of the future stream of products and investigation into the feasibility of a tall building consultancy service. A natural market growth to be targeted early is the US, Asia Pac and UAE construction markets, all undergoing tall building booms currently, with no-one currently offering this specialist service or advice.

Arup Wind Engineering, a subsidiary of the world's largest consultant structural engineering company, have been approached for wind testing and commented that this concept is ground breaking in an area not previously envisaged.

Products – the Think Tall Tools

The first two tools to be ready for market first are the Lifting Wing and the Mag-Spanner:

The Lifting Wing allows the potential of lifting construction loads in higher than currently acceptable wind speeds as it gives the load more predictable and more controllable wind profile. The result is safer lifting in higher and gustier wind-speeds. This will reduce the industry accepted norm of 40% down time for the tower crane, saving time on the critical path of the tall building construction programme and hence
substantial costs. ‘Winding off’ is the term used to describe when the wind speed is such it makes the load on a tower crane unstable and act unpredictably, or if the driver feels uncomfortable with the risk of continuing. It is interesting to note that this may occur at wind speeds of less than half that designed as operationally acceptable by the crane manufacturer. Weather forecasts show the UK climate is getting more adverse with higher wind speeds expected to more regularly occur over more months.

It can be demonstrated that main contractor preliminary costs on a typical UK tall building are in the order of £200,000 per month (including site staff, offices, crane hire etc) and the typical tall building construction programme is 36 months (three years), with the tower crane being critical for 26 months (two years). The existing industry accepted down time of 40%, equating to 10 months (due to several possible factors, but the most common of these is winding off). Conservatively estimating the Lifting Wing only saves 20% of this crane down time equates to a cost saving of 2 months at £200,000 per month = £400,000 over the construction period of a typical UK tall building.

The Lifting Wing is therefore potentially a high cost / high revenue tool either rented or sold to construction companies. There could feasibly be up to four per site, depending on the size of the loads to be lifted and number of tower cranes required to lift in higher winds. Cost of production would be comparatively cheap, estimated to be in the order of £2000 per unit, with an expected life span of 5 years due to wear and tear on site. Maintenance would be minimal, but checking and re-certification would be undertaken annually.

The Lifting Wing could be sold in the region of £15,000 - £20,000 without being excessively priced for the typical tall building main contractor or crane hire company consumables budget. Especially when demonstrated that the Wing can save circa £6500 per salvaged lifting day, therefore only needs to save 3 days to pay for itself! Alternatively it could be rented at a monthly rate to be calculated.

The Mag-Spanner is a magnetised hand tool to be used by structural steel frame erectors in the bolting up of steel beams and columns. A pair of Mag-Spanners are connected by lanyard to the steel fixer’s tool belt. One is used to securely hold the bolt and washers, another holds the nut and washers allowing safe bolting up without the risk of dropping these items from height. Items such as these are potentially lethal when falling from in excess of 10m and is currently a major health and safety risk on all steel framed building over two storeys, not isolated to tall buildings alone.

The Mag-Spanner is a low cost, medium return tool, sold to steel erection companies to issue to their men. There could be up to twenty per site as they are used in pairs and bigger projects commonly have two teams of five steel erecting crews. Cost of production would be very cheap, estimated to be in the order of £5 per unit, with a life span of circa 10 years. Maintenance would be the offer of free re-magnetising should it be necessary. The Mag Spanner could be sold for £100 per pair, equating to the cost of a good quality pair of wrenches. Lanyards could be sold separately as they may wear out.
Both tools are unique, with nothing similar being offered in the UK market, or internationally.

The intellectual property of these tools is currently protected by International Online Copyright Registration and are about to be internationally patented on receipt of funding.

The Market

The tall building market is highly segmented. It is a very specialist, high value market with many contracts negotiated rather than tendered, as lowest cost is not the way to procure the level of quality service and product demanded. As already highlighted in the Executive Summary, research undertaken in 2007 shows the average UK tall building is circa £200million pounds (Net Trade Cost) and. This specialist market sector is forecast over the next 3-5 years to be worth circa £10billion (NTC). Growth is forecast conservatively as 5% annually, until 2012, when construction forecasts are uncertain due to the completion of the Olympics and potential downturn.

However economic history shows us that key foreign market construction industries will boom whilst the UK is potentially slowing down, offering the ideal opportunity for then established UK Think Tall Company to expand operations overseas.

The market opportunity that this company addresses is the current boom in demand for UK tall buildings, directly comparable in size to the skyscraper boom of Manhattan Island in the 1920’s. Every tall building construction company worldwide must be seen to build the highest quality, in the fastest and safest manner to win these prestige projects. The innovative tools produced by the Think Tall Company will be in demand from every one of these specialist construction companies.

Business Strategy

The Think Tall Company will be in a competitive marketplace. It is entering a niche market with new products offering the key point of difference. A market analysis has been undertaken using Porters Five Forces and a SWOT matrix.
Power of Suppliers: The power of suppliers will be weak as there are large numbers of potential suppliers and intense competition amongst them, including overseas companies.

Threat of new entrants: The barriers to entry into this sector are high as it is highly specialized knowledge. Risks of copying these products would be overcome through international patented technologies. If not adequately protected, a rash of copy products could swamp the marketplace and endanger the established high quality reputation.

Power of buyers: The power of buyers in this industry is high. A relatively small number of customers control the market. However, the innovative technology offered by the Think Tall Company would serve to mitigate this power.

Threat of substitute products: At present there is no known or likely prospect of products that can substitute for the Think Tall Tools in this market sector. The threat of substitutes is low provided patents are in force.

Rivalry amongst existing firms: There are no direct competitors. The closet is the Plant and Tool hire market, rivalry amongst them is strong, leading to heavy price competition. However the strategy would be either to sell direct to the main contractors via the client, tower crane suppliers or form an alliance with the two Preferred Suppliers of Bovis Lend Lease’s Supply Chain.
SWOT Analysis (Internal & External)

The Internal Strengths and Weaknesses of the Think Tall Company, and the External Opportunities and Threats it faces, can be summarised as follows:

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>OPPORTUNITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Alliance with Bovis Lend Lease</td>
<td>● Growing, very lucrative market sector</td>
</tr>
<tr>
<td>● Innovative technology</td>
<td>● Huge potential savings to customers</td>
</tr>
<tr>
<td>● Professional management</td>
<td>● No rival products</td>
</tr>
<tr>
<td>● Low cost base, high revenue</td>
<td>● Current widespread Tall Building Client dissatisfaction with build periods and wind risk</td>
</tr>
<tr>
<td>● Ability to expand production swiftly</td>
<td>● New consumers entering the market as tall residential is the trend across UK</td>
</tr>
<tr>
<td>● Ability to shift production overseas, reducing costs</td>
<td>● Growing overseas tall building markets, US, Asia Pac, UAE</td>
</tr>
<tr>
<td>● Low production lead times</td>
<td></td>
</tr>
<tr>
<td>● Low capital consumption, high revenues</td>
<td></td>
</tr>
<tr>
<td>● Detailed knowledge of specialist market and key players</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WEAKNESSES</th>
<th>THREATS</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Low resources</td>
<td>● International Copyright for intellectual property and products not in place</td>
</tr>
<tr>
<td>● Lack of sales experience</td>
<td>● Undercut by copy-cat technology from main tool hire companies</td>
</tr>
<tr>
<td>● Dependence on suppliers</td>
<td>● Potential economic recession could impact on construction spending</td>
</tr>
<tr>
<td>● Wind tests not yet complete</td>
<td>● Downer if involved in a safety incident on site</td>
</tr>
<tr>
<td>● Industry expert opinions not yet gained</td>
<td></td>
</tr>
<tr>
<td>● HSE approval will be reqd.</td>
<td></td>
</tr>
</tbody>
</table>

The Think Tall Company’s strengths will allow for exploitation of the opportunities in the market. This innovative technology has no current rivals, leaving this company solely placed to take advantage of the existing dissatisfaction amongst tall building clients with the period of build, safety of the build process and desire to reduce levels of risk. Both products go toward solving these issues.

Current weaknesses and threats will be mitigated by securing patents and intellectual property rights, conducting wind test to prove the aerodynamic theory, gaining industry opinions, conducting full sized trials and determining a detailed sales V’s leasing strategy. The existing alliance with Bovis Lend Lease and detailed knowledge of expert organisations, will allow the speedy acceptance of the products once trials are completed. On the product side, the company will be less vulnerable to price competition because of the lower costs involved in the production of the technologically innovative products.
Marketing Plan

The major marketing activities that the company plans to undertake include:

- The core strategy for getting tall building clients on board to encourage recommended selling direct to main contractor’s and possibly key plant hire companies and crane suppliers.

- The tall building client and the main contractor will be made aware of the products through articles planned to be published in recognised industry professional and academic journals, followed by an advertising campaign in the same publications. Additionally, direct contact will be made to key potential clients through existing industry contacts.

- The potential secondary client, the plant-hire or tower crane suppliers will be made aware by the same three methods.

- The Thinking Tall Company will launch an educational website offering free advice to customers on the details and test results of the two existing tools, to be supplemented as further tools are developed.

The targeted marketing approach will achieve widespread exposure in a short timescale and will allow relationships to be quickly forged with key clients establishing the products firmly in the marketplace.

Sales and Distribution

The major marketing activities that the company plans to undertake include:

- A sales force will be hired as demand increases. This could either be developed in-house or a potential alliance could be formed with Speedy Hire, BLL’s preferred construction equipment and plant-hire company. They would be paid an intermediary margin of circa 1% for the current range of products.

- The products would be warehoused in Windsor, offering good access into London, the key UK tall building market location. Mag Spanners would be dispatched using a courier service, the Lifting Wing would be delivered via flatbed Lorries. Initially, a contract would be entered into with a local Sales & Distribution outfit that offer the entire service.

- Customers would be invoiced with the delivery of the product and followed up in 14 days.

- Settlement terms would be payment in 14 days on receipt of delivery, or if leased, payment of delivery and first months rent on delivery, each following month paid in advance.
Production Strategy

The production strategy that the company plans to undertake includes:

- A contract would be entered into with a number of production plants either contracting the entire production, or license the technology. Tenders will be sought on both forms and the most efficient method selected.

- Different production facilities would be required for the Lifting Wing which requires laying up of clear plastic over a lightweight carbon fibre frame, and the Mag Spanner which requires lathwork and metal tooling. Quality assurance procedures would form part of the contract for both production facilities.

- The total production cost per unit has not yet been established, but will be determinable upon the completion of the full scale mock-up and decisions on the most efficient material usage.

- The product lead-times will also be determinable on completion of each mock-up.

- Policies would be set up covering limited stock holding to ensure that stock does not consume too much working capital and ensuring sufficient lead time for component reordering.

- Production capacity would be established as part of production the tendering process.

Provisional Costs / Revenue

The amount of finance needed to execute this plan has not yet been determined. This will be answered in the next stage following the completion of wind testing, mock-up testing and production tendering.

The potential methods of fund raising include approaching Lend Lease Ventures, Business Angels, Venture Capitalists, Bank Finance, or a mixture of these.

Money raised will be utilised on executing this business plan, establishing demand for and stock of the existing tools and commencing development on the next suite of tools and services.

Investors capital and return would be released via an agreed percentage of sales revenue and through a trade sale, flotation, or a management buy-out envisaged within 5 years.
Conclusion - Evaluation of the Exercise

Following on from the bewildering array of definitions of the ‘Entrepreneur’ discovered in the first assignment, the literature review for this assignment shows there is an equally wide variety in the academic views on writing of business plans and their inclusions. Research even seems inconclusive as to whether writing a good business plan lends to a successful business, rather, the main body of research seems to focus on not having a business plan leading to the failure of a business (Baechler 1996, Labich 1994, Perry 2001). However, several academics were found that extolled the virtues of a good business plan (Hormozi et al’s 2002, Maranville 1999, O’Hara 1994, Sahlman 1997), with Maranville’s quote ‘failing to plan is planning to fail’ and Hormozi et al’s quote ‘If you don't know where you are going, any path will get you there’ ringing true to the writer.

Of these positive viewpoints, Sahlman details a simplistic approach to business planning in the Harvard Business Review (1997). His logic was followed, but embellished to suit the needs of the Think Tall Company.

The writer found the exercise initially frustrating, but eventually extremely satisfying. Completing the business plan process for the first time (excluding the financial side) and capturing the full potential of one idea as an entrepreneurial opportunity was something the writer had meant to do for years, but never actually got down to it. Initially it was difficult to concentrate solely on one or two ideas and capture the next steps in the development process. The temptation was to ‘concept brainstorm’ and list out hundreds of different potential product ideas.

The second difficulty was keeping the plan short and concise, not attempting to capture all relevant date in this one document. Determining details of the most suitable marketing, sales and production strategies had not been previously done and caused much difficulty, requiring constant direction from the literature review.

Finally, the writing of this business plan crystallised the scale of the opportunity for this endeavour, and the fact that no-one else is looking into this area. It also forced the realisation of two design problems and one marketing and sales problem that need to be overcome – several influential industry bodies will need to be won over to ensure this venture ‘has legs’. In the classic catch 22, these cannot be resolved until sufficient international patenting is in place protecting the intellect – itself an expensive process requiring funding.
References


APPENDIX F  COUNCIL ON TALL BUILDINGS AND URBAN HABITAT (CTBUH) QUESTIONNAIRE
Introduction

This questionnaire is targeted at the tall building industry specialists attending the CTBUH 8th World Congress to enable the best possible specialist data to be captured. It has been designed to corral the views of the wide spread of specialists within the tall building sector of the construction industry and determine the state of the art of building tall.

The Information gleaned will be treated confidentially and utilised in an Engineering Doctorate research being undertaken by the author, Ian Skelton, at Loughborough University’s Centre for Innovative and Collaborative Engineering, sponsored by Bovis Lend Lease.

The Engineering Doctorate is investigating innovation in the construction of tall buildings. The ultimate aim is to improve aspects of the construction process. Findings from this research will be published in academic and professional journals (details to be confirmed).

The six sections should take around ten minutes to complete and can be handed to the Bovis Lend Lease representative Bill Holloway during the conference, or scanned and emailed to the author at either address below.

The author, Loughborough University and Bovis Lend Lease thank you in advance for sharing your valuable views, experience and tall building insight……Enjoy the event!

Ian Skelton

ian.skelton@eu.bovislendlease.com
i.skelton@lboro.ac.uk
Innovation in Tall Building Construction

**Note - Responses in Red:** ✓ = Median (Central tendency, calculated by ranking values in ascending order and finding mid-point);

Percentages = % of respondents selecting median response.

## 1 International Tall Building Industry – Current State-of-the-Art

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓ 62%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>✓ 51%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1 3 6 2 4 7 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UAE USA AUS CH JA KO UK</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>✓ 81%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>✓ 78%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>✓ 44%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
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<tr>
<td>7</td>
<td>✓ 42%</td>
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<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
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<tr>
<td>8</td>
<td>✓ 51%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>✓ 88%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>✓ 62%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>✓ 86%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>
2 The Build Process of a Tall Building

1. Please rate the importance of the following typical construction risks for a tall building project:

<table>
<thead>
<tr>
<th>Risk</th>
<th>Lowest Risk</th>
<th>Highest Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal contractor staff experience</td>
<td>1 2 3 4 5</td>
<td>✔️ 78%</td>
</tr>
<tr>
<td>Inclement weather (winding-off tower cranes)</td>
<td>1 2 3 4 5</td>
<td>✔️ 82%</td>
</tr>
<tr>
<td>Logistical problems (man &amp; material access, hoist / crane strategies)</td>
<td>1 2 3 4 5</td>
<td>✔️ 76%</td>
</tr>
<tr>
<td>Specialist trade contractor procurement</td>
<td>1 2 3 4 5</td>
<td>✔️ 64%</td>
</tr>
<tr>
<td>Demolition of existing building or site clearance</td>
<td>1 2 3 4 5</td>
<td>✔️ 48%</td>
</tr>
<tr>
<td>Ground conditions and foundations</td>
<td>1 2 3 4 5</td>
<td>✔️ 44%</td>
</tr>
<tr>
<td>Substructure construction</td>
<td>1 2 3 4 5</td>
<td>✔️ 47%</td>
</tr>
<tr>
<td>Superstructure cycle times / speed of erection</td>
<td>1 2 3 4 5</td>
<td>✔️ 65%</td>
</tr>
<tr>
<td>Facade installation</td>
<td>1 2 3 4 5</td>
<td>✔️ 74%</td>
</tr>
<tr>
<td>Services installation and commissioning</td>
<td>1 2 3 4 5</td>
<td>✔️ 70%</td>
</tr>
<tr>
<td>Lift installation, builders use and commissioning</td>
<td>1 2 3 4 5</td>
<td>✔️ 62%</td>
</tr>
<tr>
<td>Roof, waterproofing, cleaning and special architectural features</td>
<td>1 2 3 4 5</td>
<td>✔️ 58%</td>
</tr>
<tr>
<td>Shell and core interface with fit-out works</td>
<td>1 2 3 4 5</td>
<td>✔️ 59%</td>
</tr>
<tr>
<td>Defects completion and handover for progressive occupancy</td>
<td>1 2 3 4 5</td>
<td>✔️ 79%</td>
</tr>
</tbody>
</table>

2 Would you embrace and promote an innovative construction approach on your tall building project over a tried and tested construction technique (eg. use of a new crane lifting accessory to reduce the effect of wind on material lifts)?

3 In your experience, can a typical tall building concrete frame be built from one floor to the next (floor cycle time) averaging: 2-4 days, 5-7days, 8-10 days, More? (Leave blank if unknown)

4 In your experience, can a typical tall building steel frame be built with an average piece rate of (number of pieces of structural steel erected per crane per day): 6-10, 11-15, 16-20, 21-25, More? (Ditto)
### 3 Tall Building Principal Contractors (Main Contractors, Construction Managers, Management Contractors)

1. **Do you believe tall building principal contractors offer a good safety analysis and value (or buildability) analysis of the design at preconstruction stage?**
   - **Strongly Disagree**: 63%
   - **Strongly Agree**

2. **Do you believe involving the principal contractor at an early stage in the tall building design assists in delivering value, safety, programme and cost certainty?**
   - **Strongly Agree**: 76%

3. **If you are involved in a tall building project at present, what is the principal contractor procurement route: Traditional / Design and Build, Two Stage Lump Sum, Construction Management, Management Contracting, Other/Currently undefined?**
   - **Traditional / Design and Build (T/D&B)**: 41%
   - **Two Stage Lump Sum (2SLS)**
   - **Construction Management (CM)**
   - **Management Contracting (MC)**
   - **Other/Currently undefined**

4. **Do you believe that procurement route options are restricted on tall buildings due to the limited number of high quality, capable principal contractors?**
   - **Strongly Agree**: 81%

5. **Do you believe Construction Management is the current preferred procurement route of for a tall building principal contractor and will continue to grow in favour?**
   - **Strongly Agree**: 53%

6. **Do you believe previous tall building experience is fundamental in the selection of a principal contractor for a tall building project?**
   - **Strongly Agree**: 88%
7. Please rate the importance of the following overall tall building project risks:

<table>
<thead>
<tr>
<th>Risk</th>
<th>Lowest Risk</th>
<th>Highest Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Securing finance</td>
<td></td>
<td>✓ 63%</td>
</tr>
<tr>
<td>Securing tenant pre-lets</td>
<td></td>
<td>✓ 58%</td>
</tr>
<tr>
<td>The design process meeting expectation</td>
<td></td>
<td>✓ 65%</td>
</tr>
<tr>
<td>Construction safety</td>
<td></td>
<td>✓ 53%</td>
</tr>
<tr>
<td>Programme surety</td>
<td></td>
<td>✓ 72%</td>
</tr>
<tr>
<td>Cost control / certainty</td>
<td></td>
<td>✓ 76%</td>
</tr>
<tr>
<td>Build quality</td>
<td></td>
<td>✓ 78%</td>
</tr>
<tr>
<td>Declining demand in the tall building market</td>
<td>✓ 72%</td>
<td></td>
</tr>
<tr>
<td>Regulations and statutory requirements</td>
<td>✓ 48%</td>
<td></td>
</tr>
</tbody>
</table>
8. Please rate the importance of the following list of principal contractor key attributes that you would consider in their selection for a tall building project:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Least</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63%</td>
</tr>
<tr>
<td>Provision of an experienced tall building team</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>82%</td>
</tr>
<tr>
<td>Innovative build approach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>55%</td>
</tr>
<tr>
<td>History of cost certainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>53%</td>
</tr>
<tr>
<td>History of programme certainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>57%</td>
</tr>
<tr>
<td>Logistics management efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>59%</td>
</tr>
<tr>
<td>Safety record</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Design management ability</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Value management ability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>58%</td>
</tr>
<tr>
<td>Ability to offer project funding</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Procurement expertise</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Established specialist supply chain</td>
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<td></td>
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<td></td>
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<td></td>
<td>59%</td>
</tr>
<tr>
<td>Political connections</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>60%</td>
</tr>
<tr>
<td>Rank or position held in the construction industry</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Local knowledge and experience</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56%</td>
</tr>
</tbody>
</table>
4 Wins and Losses Inherent with Building Tall

Please describe your personal experience of a memorable ‘win’ and ‘loss’ on a tall building project you have been involved in. These could be from any project phase from detailed design development, through construction to completion, handover and occupancy of the building.

‘Wins’ are defined as things that were done well on a tall building project that significantly contributed to the success of the construction process.

‘Losses’ are defined as things that were not done well on a tall building project that negatively contributed to the construction process.

Wins on my Project:

Losses on my Project:
5 New Techniques from Overseas or Other Industries

Please describe any ideas, new techniques or practices you have seen that could be adopted in the construction process of a tall building project. These ideas could be from overseas construction methods, other industry practices or just areas where the traditional building approach seems outdated and in need of a fresh approach. They could cover any project phase from detailed design development, through construction to completion, handover and occupancy of the building:

6 Your Details (Optional)

Your Current Tall Building Project Name and Description:
- Office
- Residential
- Mixed Use
- Other (Please Specify)

Your Company is a:
- Tall Building End User or Client
- Tall Building Investor or Developer
- Tall Building Design Team Member or Consultant
- Tall Building Specialist Contractor or Specialist Supplier
- Tall Building Principal Contractor
- Other (Please Specify)

Email: 
Name:
Position:
Company Name:
Tall Building Name: