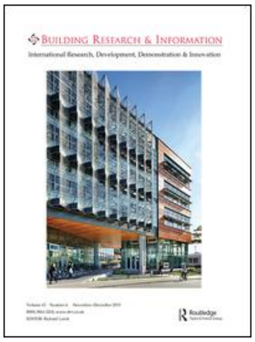

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RESEARCH PAPER

Construction costs comparison between 'green' and conventional office buildings

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The actual construction cost of certified green office buildings in New Zealand is compared with conventional buildings. Although a large body of research exists on the financial and environmental benefits of green buildings, there is little evidence on capital cost implications for building green. This study serves as the first empirical study to analyse detailed cost plan data in New Zealand to quantify the impact of green building on construction cost. Data from 17 Green Star NZ v1-certified office buildings were paired with a set of modelled cost estimates derived from the Davis Langdon *Blue Book* and the *Rawlinsons New Zealand Construction Handbook* (the authoritative published sources for New Zealand construction cost data). The paired data were analysed across five panels using the non-parametric Wilcoxon matched-pairs signed ranks test. When benchmarked against the modelled costs, green building construction costs were higher on average, but the difference was not statistically significant. This was true across all five panels tested: the entire green building dataset, mid-rise buildings, high-rise buildings, 4 Green Star-rated buildings, and 5 and 6 Green Star-rated buildings. Each panel featured buildings that were above comparative costs as well as several whose actual costs were below modelled estimates.

Keywords: capital cost, construction, cost, green building, Green Star, office buildings, sustainability

Le coût de construction réel des immeubles de bureaux certifiés verts en Nouvelle-Zélande est comparé à celui des immeubles classiques. Bien qu'il existe un important corpus de recherche sur les avantages financiers et environnementaux des bâtiments verts, il y a peu d'éléments probants sur les implications en termes de coût du capital pour la construction de bâtiments verts. Cette étude constitue la première étude empirique qui analyse les données des plans détaillés des coûts en Nouvelle-Zélande pour quantifier l'impact du bâtiment vert sur les coûts de construction. Les données provenant de 17 immeubles de bureaux certifiés Green Star NZ v1 ont été couplées à une série d'estimations modélisées des coûts tirée du *Livre Bleu* de David Langdon et du *Rawlinsons Manuel de Construction de Nouvelle-Zélande* (les sources publiées qui font autorité concernant les données relatives aux coûts de construction pour la Nouvelle-Zélande). Les données couplées ont été analysées sur cinq panels en utilisant le test non paramétrique des rangs signés de Wilcoxon pour échantillons appariés. Lorsqu'ils ont été comparés aux coûts modélisés, les coûts de construction des bâtiments verts étaient supérieurs en moyenne, mais la différence n'était pas statistiquement significative. Ceci s'est vérifié sur la totalité des cinq panels testés : l'ensemble des données des immeubles verts, les immeubles de hauteur moyenne, les immeubles de grande hauteur, les immeubles classés Green Star 4, et les immeubles classés Green Star 5 et 6. Chaque panel comprenait des immeubles qui se situaient au-dessus des coûts comparatifs, ainsi que plusieurs dont les coûts réels étaient inférieurs aux estimations modélisées.

Mots clés: coût du capital, construction, coût, immeuble vert, Green Star [Etoile Verte], immeubles de bureaux, durabilité

Introduction

Buildings are substantial CO_2 emitters and contribute to climate change. A recent study carried out by the United Nations Environment Programme (UNEP) suggested that the residential and commercial building sectors are responsible for approximately one-third of the greenhouse gas emissions of developed countries (UNEP, 2009), and the property sector's impact on the environment is not limited to carbon emissions and energy, with buildings in the European Union consuming 16% of potable water, 50% of raw materials and accounting for 40% of solid landfill waste (Keeping, Dixon, & Roberts, 2007). Green building is viewed as a method of responding to these environmental issues. To facilitate this, many organizations, such as the New Zealand Green Building Council, have introduced rating tools to recognize and improve the sustainability of the building stock.

The era of rating tools commenced in 1990 with the introduction of the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK. This was followed in 2000 by the US tool: Leadership in Energy and Environmental Design (LEED). The Green Building Council of Australia was founded in 2002 and used BREEAM and LEED as the basis for its Green Star rating system, which is specific to the Australian environment and building practices (Madew, 2006). More recently the New Zealand Green Building Council was established in 2006 with its first rating tool, Green Star NZ v1, launched in 2007 (for a detailed history of international rating tools, see Reed, Bilos, Wilkinson, & Schulte, 2009). Despite the overwhelming evidence that buildings negatively impact the environment, the adoption of green building practices still faces headwinds. The primary obstacle is the perception that is costs more to build green.

Background

The bulk of the literature on green buildings focuses on the benefits to building owners, society at large, the environment and, in particular, building users (for a recent survey of user perception and satisfaction, see Baird, 2010). However, a much smaller portfolio of research has investigated the obstacles to building green such as higher construction costs, with the work of Kats, Alevantis, Berman, Mills, & Perlman (2003) and Kats *et al.* (2010) being the most cited. According to Hwang & Tan (2012) perceived cost premiums remain the main hindrance to the uptake of green buildings. Of the research on cost implications of sustainable construction, most studies explore theoretical issues surrounding green building costs rather than explicitly testing for cost premiums.

Some researchers have argued that green building soft costs are higher than conventional projects due to incremental costs associated with the process of achieving a green building rating. This involves both application costs as well as additional consulting required under the various rating tools (Cupido, Baetz, Pujari, & Chidiac, 2010; Owen, 2006). Other studies such as Malin (2000) have considered the component costs of green buildings. Malin investigated cost premiums associated with particular green materials and found that although they have higher initial costs, the added expense is not severe if the life cycle cost (LCC) is considered. This accounting technique, which considers green building costs and benefits over a building's entire life, is discussed by Cole & Sterner (2000, p. 369) who stated that although LCC accounting is superior to initial capital cost alone it:

> remains a limited approach to account for the broader environmental and social costs associated with buildings.

Cole and Sterner reasoned that these broader cost savings associated with the construction of green buildings should be factored in along with operating benefits such as lower energy and water consumption.

Some of these '*social costs*' such as greenhouse gas emissions have since been monetized through carbon pricing, although these externalities may still be priced too low. More recent LCC research by Kneifel (2010) suggests that by implementing energy efficiency measures commercial buildings can reduce their carbon footprint by 16% on average, thereby improving green buildings' life cycle cost-effectiveness.

Some argue that if integrative design techniques are properly employed, green buildings should cost less than conventional counterparts. In their research paper, Hydes & Creech (2000) used two case studies to demonstrate the potential to achieve green objectives such as increasing the thermal and lighting efficiency of the building in ways that reduce, rather than increase, initial capital costs. The authors also implored architects and engineers to be innovative and daring by considering the use of salvaged building materials and equipment the further to lower both embodied energy and initial cost.

Other researchers have claimed that higher green building costs are mere illusions. Bartlett & Howard (2000, p. 324) asserted that quantity surveyors:

> seriously overestimate the capital costs of energy efficient measures and seriously underestimate the potential for cost savings

thereby misleading decision-makers. Bordass (2000) shared this sentiment and argued that market participants' perceptions of higher construction costs are unsubstantiated. However, with the exception of

Table 1 Summary of perception survey findings on green building cost savings/premiums

Author(s) (year)	*N*	Cost savings (%)	None (%)	Cost premiums (%)		
				1–5%	6–10%	Over 10%
Park, Nagarajan, & Lockwood (2008)	16	0	0	37	38	25
Breslau (2007)	414	1	8	38	30	22
Building Design+Construction (2007)	631	1	13	24	27	35
Ahn & Pearce (2007)	87	1	15	23	34	27

owner-occupied non-residential buildings, commercial buildings tend to be multi-tenanted and feature leases that are 'net' of operating expenses. Therefore, the revenue benefits from a green building's energy savings flows to the tenants rather than the building owner who has funded the efficiency measures.

In terms of research that has explicitly investigated green building costs, four surveys have been conducted to date that studied perceived cost premiums. These surveys asked respondents the degree to which they believed green building costs differed from conventional buildings. Table 1 summarizes these surveys' findings.

The Deloitte study by Park, Nagarajan, & Lockwood (2008) reported that none of the survey's 16 respondents felt that green buildings cost the same or less than non-green buildings. All respondents perceived green buildings as costing more, with the mode response being that there exists a cost premium of between 6% and 10%. Breslau (2007) presented the results of a similar perception survey conducted by Jones Lang LaSalle and CoreNet Global. Unlike the Deloitte study, 8% of survey respondents felt that the cost premium was neutral, while 1% perceived that green buildings cost less to design and build. Nevertheless, 90% of respondents indicated that there is a green building cost premium.

Building Design + Construction (2007) found that of 631 survey respondents, 86% believed green buildings cost more, 13% stated that they cost the same and 1% felt that green buildings are less expensive. The mode response was that there exists a green cost premium of more than 10%. Ahn & Pearce (2007) recorded very similar results from a survey of 87 construction-related firms. In summary, although the estimated green building cost premium varies across the different perception studies, these studies clearly indicate that US property professionals hold the view that green buildings cost more than non-green buildings.

In addition to perception surveys, several studies have analysed actual or modelled green building construction cost data in order to determine prevailing cost differences. As with the perception studies, this research has primarily been carried out by professional services firms rather than academic researchers. Consequentially, very few of these studies are transparent in terms of methodology, few subject their data to meaningful statistical tests, and none has been subjected to a rigorous peer-review process. Rather, the analytical research to date has either come from government-

Table 2 Summary of UK BREEAM cost study

Author (year)	Cost premium estimation method	Number of green buildings	Building type	Green building cost premiums (%)		
				Good	Very good	Excellent
Rawlinson (2007)	Actual green building costs with green-specific costs itemized	1	Office building	Not studied		2.8
Building Research Establishment (BRE), Centre for Sustainable Construction & Cyril Sweett Sustainability and Cost Consulting Teams (2005)	Actual green building costs against model costs to Building Regulations standards	4	Office building, house and healthcare	0–0.22	0.1–5.7	3.3

commissioned reports or was undertaken by professional services firms actively involved in green building projects. The most noteworthy of these firms is Davis Langdon, a global quantity surveying firm, that has published much of the analytical research into green building costs.

Tables 2–4 provide a summary of the quantitative research conducted in the United Kingdom, United States, Australia and New Zealand that has investigated the impact of building green on construction costs. As with the present study, the focus is on hard construction costs (labour, materials, installed equipment, etc.) with soft costs (design, project management, compliance, government levies, etc.) typically omitted.

In terms of the comparison methods used in the above studies the predominant approach has been to compare modelled green building costs against modelled conventional building costs. A minority of studies has analysed actual cost data with the studies by Matthiessen & Morris (2004, 2007) and Davis Langdon (2009) being the only research that has compared actual green building costs with actual non-green building data. All three studies

Table 3 Summary of US LEED cost studies

Author(s) (year)	Cost premium estimation method	Number of green buildings	Building type	Green building cost premiums (%)			
				Certified	Silver	Gold	Platinum
Kats *et al.* (2010)	Survey respondents' (primarily architects) stated '*green premium*' estimates	37	Office buildings	1.20	2.25	3.37	7.66
		29	Schools	0.35	1.00	1.30	9.60
		17	Academic buildings	1.65	1.80	1.93	2.53
Davis Langdon (2009)	Unpaired *t*-test of actual green fit-out costs against 13 non-green fit-out costs	12	Office interior fit-outs	No statistically significant cost difference			
Matthiessen & Morris (2007)	Unpaired *t*-test of actual green building costs against non-green building costs within each building type	17	Academic buildings	No statistically significant cost difference			
		26	Laboratories				
		25	Libraries				
	Unpaired *t*-test of actual green building costs against 22 non-green building costs	15	High-rise apartments				
Nilson (2005)	Actual green building costs with green-specific costs itemized	1	Office building	Not studied		0.82	Not studied
Steven Winter Associates (2004)	Model green building costs against model costs to 'federal design requirements'	2	Office building and courthouse	1.4–2.1	3.1–4.2	7.8–8.2	Not studied
Matthiessen & Morris (2004)	Unpaired *t*-test of actual green building costs against 98 non-green building costs across all building types	45	Academic buildings, laboratories and libraries	No statistically significant cost difference			
Kats, Alevantis, Berman, Mills, & Perlman (2003)	Survey respondents' (primarily architects) stated '*green premium*' estimates	33	Schools and office buildings	0.66	2.11	1.82	6.50
Northbridge Environmental Management Consultants (2003)	Meta-analysis of '*secondary research*' and unspecified analysis of actual cost data	1	Generic, fictitious building	Soft costs: 1.5–3.1 Hard costs: 3–8			
Packard Foundation (2002)	Model green building costs against model 'market' cost	1	Proposed, new office building	0.9	13.1	15.5	21.0

Table 4 Summary of Australasian Green Star cost studies

Author(s) (year)	Comparison method	Number of green buildings	Building type	Green building cost premiums (%)		
				4 Star	5 Star	6 Star
Fullbrook & Woods (2009)	Actual ecological sustainable development (ESD) costs against non-green model costs	1	Generic, fictitious government office fit-out	1.25 (4 Star building) 2.91 (unrated building)	4.37 (5 Star building)	6.23 (5 Star building)
Davis Langdon (2007)	Model green building costs against generic, non-green model costs	1	Generic, fictitious office building	0	3–5	9–11+
Fullbrook (2007)	Model green building costs from developer proposals against non-green model costs	20	Office buildings	3 (Class A) 7 (Class B)	7 (Class A) 15 (Class B)	Not studied
Fullbrook, Jackson, & Finlay (2005)	Actual '*ecologically sustainable development*' costs against non-green model costs	1 1 1 1	Academic building Hospital School Library	−15 (savings) 1.5 5.7 4.9		
	Model ESD office building costs against non-green model costs	1	Office building	Low/medium ESD: 6.5 Medium/high ESD: 11.5		

were produced by Davis Langdon employees and all concluded that there is no statistical evidence that green buildings cost more than non-green buildings. All other studies have found that green buildings tend to cost more and the premiums increase with higher rating levels. The highest recorded premiums were found in the earliest analytical study by the Packard Foundation (2002) with LEED Platinum-rated buildings incurring a 21% premium. However, most found lower premiums within 10% of conventional building costs.

The most cited studies on green building cost premiums are Kats *et al.* (2003, 2010). As with many other studies, Kats *et al.* analysed several building types including offices but they employed an entirely different approach to measuring cost premiums. Rather than comparing actual or modelled costs, Kats *et al.* conducted a mail questionnaire survey with a single question responsible for quantifying cost premiums, which asked:

> What was the additional cost incurred (the cost premium) to construct a green building vs. a conventional building?

This method is problematic for a number of reasons. Firstly, the survey itself would be subject to self-selection bias. In the case of the 2010 study, over 300 surveys were mailed but only 170 responses were received, seven of which did not reply to the cost premium question. Therefore, the analysis on cost reflects the opinions of the survey recipients who elected to respond.

These respondents were predominantly the principal architects of the LEED-certified green buildings targeted by the survey and are not likely to be impartial in their views towards building green. It would be in the interest of such respondents, who have experience in designing green buildings and a strong desire to be instructed on further LEED-certified projects, to err on the lower end of the green cost premium spectrum. This is particularly the case since all respondents are named in footnotes throughout Kats *et al.* (2003) and within Appendix B of Kats *et al.* (2010). It is conceivable that a respondent associated with projects featuring low green building cost premiums would be more likely to be instructed by a would-be green building developer than would a respondent linked to projects with high cost premiums. Neither of Kats *et al.*'s publications clarify whether or not respondents were notified that their names would be disclosed in the subsequent research publication, but given that this is the case it may be reasonable to assume that one of the possible incentives for participating was promotion of their services in the publication. In addition to issues of respondent bias, the authors' choice of directing the surveys to architects rather than quantity surveyors to ascertain green building cost premiums is also somewhat problematic as cost estimation is generally not a core competency of practising architects whereas quantity surveyors specialize in this very task.

Kats *et al.* (2010) included in their Appendix C the entire green building dataset. The present analysis of the Kats *et al.* data found that 24% of Certified, 26% of Silver and Gold, and 18% of Platinum-rated buildings were recorded as incurring no green premium. The cost premiums from Kats *et al.* presented in Table 3 are derived from their Appendix C and represents mean premiums across the three main property types investigated: office buildings, schools and academic buildings.

The present study's research design addressed the issue of bias by electing to acquire and analyse actual cost data from quantity surveyors' proprietary cost plans for each of the green buildings studied. As a condition of disclosing such proprietary information, the authors agreed with each data provider that individual buildings would not be identified. It was largely this level of ensured confidentiality that enabled access to sensitive commercial cost plans.

The studies that have investigated green building costs in Australasia include three studies commissioned by the New Zealand government and a research report by Davis Langdon focused on Australian office markets. Of these the only study to analyse actual cost data was Fullbrook, Jackson, & Finlay (2005) which predates New Zealand Green Star and investigated four recently completed 'ecologically sustainable developments'. Their research found that the buildings' actual hard costs ranged from being 15% below non-green modelled costs to roughly 6% more expensive. The technique used to quantify cost premiums used in Fullbrook *et al.*'s study is similar to that by the Building Research Establishment (BRE), Centre for Sustainable Construction & Cyril Sweett Sustainability and Cost Consulting Teams (2005) which also took a case study approach and analysed the actual costs of four BREEAM-certified buildings against modelled costs of the same type of buildings constructed to Building Regulations standards. The methods of comparison between green and non-green construction costs used in these two 2005 studies are the most similar to the present study. The main difference is that the present paper investigates 17 commercial office buildings whereas Fullbrook *et al.* and the BRE *et al.* analysed a handful of individual case studies, each with a different use and nearly all case studies of public, non-commercial facilities.

Methods

The research was conducted in two stages: qualitative interviews followed by quantitative data analysis. Initially a series of semi-structured interviews was held with 15 industry professionals from across New Zealand. This included six engineers, three quantity surveyors, two architects, a developer, a building owner, a general contractor and a project manager. Each of the interviewees had first-hand experience with green buildings. The aim of the interviews was to understand the current perceptions of green building construction costs and to gauge whether the introduction of Green Star had affected New Zealand office markets. The insights gained from the interviews were drawn upon by the authors when interpreting the empirical results.

Table 5 indicates the interviewees' perceived green building cost premiums. Given the choice of between five potential responses ranging from cost savings to a cost premium over 10%, none of the interviewees responded that a Green Star-rated project would cost less than or equal to a conventional building. Most felt that 4 Green Star buildings would incur cost premiums of up to 5% while none estimated that such a project would be subject to a cost premium of over 10%. Similar to past perception studies, the cost premium varied by rating level with 5 Green Star buildings largely perceived to attract cost premiums of 6–10% while 6 Green Star projects would tend to attract premiums in excess of 10%.

Interviewees were also asked why green buildings cost more to construct. The reasons indicated included the fact that sustainable features such as green materials, high-performance cladding systems, rainwater harvesting and energy-efficient mechanical equipment could increase capital costs. They also noted the soft costs associated with applying for and satisfying the requirements of Green Star. Several interviewees stated that since Green Star entered the market, building quality in general had risen. More specifically these interviewees felt that Green Star-rated buildings tended to built to higher specifications of which many did not necessarily benefit the environment. Such high-quality design features were in addition to green building materials and systems put in place to earn a particular Green Star rating. Furthermore, the interviewees felt that this enhanced level of quality was particularly evident in the case of urban fringe developments which tended to consist of low-

Table 5 Perceived New Zealand green building cost savings/premiums

Rating	Cost savings (%)	None (%)	Cost premiums (%)		
			1–5%	6–10%	10%+
4 Green Star	0	0	75	25	0
5 Green Star	0	0	31	62	8
6 Green Star	0	0	0	40	60

Note: $N=15$ industry professionals.

and mid-rise buildings and up until the introduction of Green Star rating tools had historically been of lower quality than high-rise office buildings in central business districts.

Quantitative research

The second stage of the study involved the collection and analysis of actual green building cost data. With a focus on actual costs it was decided to target New Zealand office buildings that had been certified under the New Zealand Green Building Council's inaugural rating tool: Green Star NZ v1. Throughout the country there are 49 Green Star NZ v1-certified projects. The developer and/or owner of each building was solicited for participation in this study. Twenty-one owners, roughly 43%, agreed to contribute to the study and their respective quantity surveyors involved with each development provided access to the full project cost plan.

Four of these 21 buildings were refurbishments rather than new construction and were therefore excluded, resulting in an overall dataset of 17 buildings. Of the cost plans analysed, two were estimated costs as the projects were under construction when the data were collected. However, the remaining 15 cost plans provided final, as-built costs. Table 6 provides a breakdown of these projects by height category and Green Star rating. The dataset includes eight 4 Green Star buildings, eight 5 Green Star and one 6 Green Star building. The majority of buildings were mid-rise (under six stories). In terms of location, 12 of the buildings were located in Auckland with the balance found elsewhere in the country. The green buildings studied ranged in initial year of construction from 2006 to 2010.

The authors initially sought to gather actual cost data on non-green office buildings for use as a baseline for comparison as per Matthiessen & Morris (2004, 2007). However, this proved unfeasible. Therefore, the research was redesigned to compare actual costs with modelled costs derived from Davis Langdon's *Blue Book* and the *Rawlinsons New Zealand Construction Handbook*, which is the country's only comprehensive construction cost index. Within the Introduction the editor asserts that:

> the Handbook has achieved a reputation as the leading authority on the various aspects of construction costs in New Zealand, and is recognised as an authoritative text in the courts for cases relating to disputes in respect of construction cost.
>
> (Giddens, 2010)

Table 6 Frequency table of analysed green buildings by height and rating

Building height	4 Green Star	5 and 6 Green Stars	Total
Under six stories	6	5	11
Six stories and over	2	4	6
Total	8	9	17

While the *Rawlinsons Handbook* is a commercial publication, current and past *Blue Book*s are available for free download from the Davis Langdon website (http://www.davislangdon.com/ANZ/Research/). As previously mentioned, the authors' adopted approach of comparing actual costs to model costs aligns the present study with the comparison methods employed by Fullbrook *et al.* (2005) and BRE *et al.* (2005).

Both the *Blue Book* and *Rawlinsons Handbook* are silent in regard to the specific methodology employed to determine their cost estimates. Both are also silent in terms of whether or not green building construction costs are incorporated. To clarify the methodologies used, the authors contacted the editor of *Rawlinsons Handbook* who confirmed that its figures are based on modelled costs rather than a sampling of actual whole building construction costs and that they reflect prevailing costs for conventional buildings rather than green buildings. In contrast, the cost estimates published in the *Blue Book* are derived from tender prices rather than *Rawlinsons Handbook*'s modelled costs that track changes in construction labour and material prices.

In terms of the incorporation of green building costs the 2010 *Blue Book* (Davis Langdon, 2010) stipulates that:

> all rates generally relate to a building achieving a 4 green star rating and a 4.5 NABERS energy base building rating.

This reference is derived from the Property Council of Australia's (2006) *A Guide to Office Building Quality*. It states that new Australian office buildings will only be classified as '*Premium*' or '*Class A*' if they achieve these stated green ratings or higher. The updated 2012 guide (Property Council of Australia, 2012) is even more specific with '*Premium*' class buildings requiring either a 5 Green Star or 5 star NABERS (National Australian Built Environment Rating System) rating. This means that in the Australian office market, high standard buildings must be green, which in turns suggests that green buildings are not only sustainable, but also constructed to a high standard in general. Based on the specifications of the analysed green buildings evident in the cost plans, the authors believe that this green–high standard nexus exists in New Zealand office markets as well.

In an attempt to gauge the accuracy of cost information contained within the *Blue Book* and *Rawlinsons Handbook*, cost data were compared between the two sources. Specifically, the *Blue Book*'s 'medium-rise standard offices' costs were paired with *Rawlinsons Handbook*'s '3 to 5 storey office buildings with A/C' and 'high standard [high-rise] offices' costs were compared against figures for '6 to 15 storey office buildings with A/C'. The variation in the two publications' mean office building construction costs for Auckland and Wellington from 2006 to 2009 is roughly 5%. However, the publications' high-rise office figures diverge in 2010 with *Rawlinsons Handbook* including slight price increases from the previous year while that year's *Blue Book* records a considerable drop in high standard office building hard costs putting it on par with its 2006 figures. This was unlikely to be a typographical error on the part of Davis Langdon, given that the 2011 *Blue Book* further reduced high standard office costs. Instead, the drop in construction prices likely mirrors a drop in tender prices, which *Rawlinsons Handbook*'s methodology fails to capture.

Importantly, only the *Blue Book* explicitly provides an indication of cost differences between high standard and average standard office buildings. As discussed above, in Australasia green buildings tend to be high-standard buildings and therefore high-standard construction. This is specifically the case for the population of 17 green buildings being studied. Therefore, cost estimates for high-standard buildings are needed to establish whether or not green buildings are subject to cost premiums. Given the *Blue Book*'s recognition of differences in standard and the fact that its methodology appears to reflect better movements in tender prices, the authors have chosen it as the main source for producing model construction costs.

Since the *Blue Book* provides high-standard costs for only high-rise buildings (over ten stories), an implied high standard '*premium*' can be derived by computing the cost difference between 'High Standard [High-rise] Office' and 'Average Standard High-rise Office'. This amount can then be added to average standard low- and mid-rise costs to approximate the high-standard costs for these categories of buildings, which account for 15 of the 17 green buildings analysed.

Once the model cost source was determined the next step was to pair individual green buildings with their respective annual *Blue Book* model costs. For consistency, the year of initial construction was used to determine the handbook from which modelled costs would be derived. Aside from building scope (*e.g.* three to ten storey mid-rise) cost estimates are given for three New Zealand cities: Auckland, Wellington and Christchurch (from 2010 onwards). In the seldom case when an analysed green building project is located in a different city, the costs for the nearest city were used.

One challenge in comparing actual costs from non-uniform cost plans with modelled costs from the *Blue Book* is that the scope of some green buildings differ. For instance some developments include integrated fit-outs of tenanted spaces while others are constructed as 'shell-and-core' with tenants being responsible for their own fit-out. Since the cost plans were largely non-uniform as they were supplied by various quantity surveying firms, some cost plans made it difficult to isolate interior fit-out costs associated with lease spaces versus common areas. However, costs for internal finishing in general were clearly isolated in each of the cost plans.

Since the *Blue Book* is limited in its provision of cost breakdowns by building elements, the *Rawlinsons Handbook*'s section on 'Elemental Costs of Buildings' was used to quantify the internal finishing component of the modelled costs. This was done by multiplying the *Blue Book* per square metre costs by the respective *Rawlinsons Handbook*'s percentage share of costs associated with internal finishing. This amount was then removed to arrive at hard costs for 'shell-and-core' office buildings *less* the costs associated with internal finishes. Lastly several other actual costs were removed from cost plans to align them with the *Blue Book*'s costs which are defined as:

> inclusive of builders preliminaries and profit but exclusive of site works, external services, land and interest costs.

With the necessary adjustments made to actual and modelled costs, the data were tested statistically to determine if the green buildings' costs were indeed significantly higher than the modelled costs. Since the number of observations per tested group ranged between six for the set of high-rise buildings and 17 for the overall dataset, the use of a parametric test such as the paired Student's *t*-test was not feasible since such sample sizes were below the commonly accepted threshold of 30 observations (Cohen, 1988; Wilson van Voorhis & Morgan, 2007). That said, the *t*-tests conducted by Matthiessen & Morris (2007) and Davis Langdon (2009) violated this threshold. It was therefore decided to use the non-parametric Wilcoxon matched-pairs signed ranks test as an alternative to the *t*-test (for an explanation of the test procedure, see Siegel, 1956, pp. 75–83). The test considers a null hypothesis of no cost difference between the actual green building cost and *Blue Book* model cost, with the alternative hypothesis being that a green building cost premium exists.

From the semi-structured interviews, it was suggested that aside from their provision of sustainable materials and systems, Green Star-rated buildings tend to be of higher overall quality in comparison with non-green buildings. Therefore, the hypothesis testing compares

Table 7 Summary results of Wilcoxon matched-pairs signed ranks tests

Panel	Description	*N*	Above model cost	Below model cost	*W*	*z*	*p*[a]
I	All buildings	17	10	7	42	1.63	0.102
II	Three to five stories	11	7	4	15	1.60	0.110
III	Six to 15 stories	6	3	3	8	0.52	0.600
IV	4 Green Star	8	4	4	14	0.56	0.575
V	5 and 6 Green Stars	9	6	3	10	1.48	0.139

Note: [a]Directional, one-tailed significance level (*p*-value).

actual costs with the *Blue Book* model cost assuming a high standard specification.

Results

The summary results of the Wilcoxon matched-pairs signed ranks tests are given in Table 7. It provides the number of green buildings above and below the *Blue Book* model cost. It also indicates the Wilcoxon value (*W*), *z*-score and *p*-value for each test. None of the panels studied returned statistically significant differences between actual and modelled construction costs. All the panels featured a mix of observations above and below model cost, with six to fifteen storey and 4 Green Star panels having an equal number of buildings on either side of the benchmark.

Table 8 provides a frequency of cost differences between actual green buildings and modelled costs across the five panels. It indicates a wide spectrum of differences. However, the mode range in four of five panels is actual costs 0–9% *below* model costs. The exception is 5 and 6 Green Star buildings where the largest cohort features actual costs more than 50% above model costs. The variation in costs within panels indicates a considerable degree of heterogeneity among green buildings. Some of this could potentially be addressed through a larger dataset with more precisely defined panels such as three to five storey, 4 Green Star buildings. Unfortunately, the present dataset of only 17 observations does not allow for this.

Table 9 presents summary statistics of the difference between actual and model costs. The ranges and standard deviations are substantial and reflect the wide variation typical of commercial construction costs. Matthiessen & Morris (2007) noted that such cost variance reflects the heterogeneity of the commercial building stock. It is for this reason that the present authors elected to analyse their green building dataset by height category and sustainability rating. Such an approach was not taken by Matthiessen and Morris who instead elected to aggregate all green buildings into a single population regardless of individual rating levels. Moreover, unlike the present study, Matthiessen and Morris made no attempt to subdivide their datasets into more homogenous subpopulations based on the physical characteristics of the academic buildings, laboratories, libraries and apartment buildings analysed. In the present study, strictly office buildings are considered.

Despite these efforts the construction costs vary greatly within cohorts with the largest difference occurring within the panel of 5 and 6 Green Star buildings. In this case one building's actual hard cost was 35% below the *Blue Book* modelled costs while another building in the same group was roughly 96% higher

Table 8 Frequency table of green building cost differences

Panel	Description	*N*	Actual cost below model cost			Actual cost above model cost					
			20%+	10–19%	0–9%	0–9%	10–19%	20–29%	30–39%	40–49%	50%+
I	All buildings	17	2	0	5	2	1	1	1	2	3
II	Three to five stories	11	1	0	3	1	1	0	1	2	2
III	Six to 15 stories	6	1	0	2	1	0	1	0	0	1
IV	4 Green Star	8	1	0	3	1	1	0	0	2	0
V	5 and 6 Green Stars	9	1	0	2	1	0	1	1	0	3

Table 9 Summary statistics of green building cost differences

Panel	Description	*N*	%				
			Mean	Median	Standard Deviation	Minimum	Maximum
I	All buildings	17	18.2	7.2	35.2	−35.4	96.4
II	Three to five stories	11	23.3	14.5	36.4	−24.3	96.4
III	Six to 15 stories	6	8.7	2.3	33.9	−35.4	65.3
IV	4 Green Star	8	8.1	0.8	23.9	−24.3	45.2
V	5 and 6 Green Stars	9	27.2	24.4	42.2	−35.4	96.4

than estimated costs. Even the tightest cost range is considerably large. Based on standard deviation, Panel IV, consisting of 4 Green Star buildings, is the most closely clustered about the mean difference between actual and model cost. Aside from the wide variation of individual high-rise costs, the overall Panel III and IV differences between actual and model costs are exceptionally small with a mean difference around 8% and median cost differences of 2% and 1%, respectively. This along with the Wilcoxon test results suggests that, overall, green buildings in New Zealand are *not* systematically more costly to construct than conventional buildings.

Conclusions

This study provides the first in-depth investigation into actual green building construction costs in New Zealand based on detailed cost plans. With initial capital costs being the primary obstacle to the uptake of green buildings, research of this nature is vital towards understanding whether or not green buildings cost more to construct. Based on the comparison of 17 green buildings' actual cost data against modelled cost estimates, it is concluded that, on the whole, green buildings are not inherently more expensive due to their provision of sustainable materials and systems. Although the green buildings analysed have shown higher costs on average, a sizable portion of buildings have been found to be below modelled costs. As noted by Matthiessen & Morris (2007) such cost variance reflects the heterogeneity of the commercial building stock. Interestingly the largest variance is found in the cohort of 5 and 6 Green Star buildings. This group of nine buildings contains the largest cost savings (−35%) and highest cost premium (96%). This alone captures the sentiment of Hydes & Creech (2000) and other researchers that high-performing green buildings do not necessarily need to cost more. In fact they can be considerably less expensive, particularly when mechanical systems can be minimized or omitted.

Future research can address the issue of cost variance by performing similar analyses on larger office markets such as Australia, the United States or the United Kingdom. Collecting actual cost data from such sizable markets should result in a considerably larger green building dataset. With more observations gathered, more homogenous panels can be created. This was a limiting factor in the present study which had only 17 total observations. The factors by which panels can be defined could include combinations of rating level and building scope (*e.g.* 4 Green Star high-rise buildings) as well as building quality based on expert classifications (*e.g.* Property Council of Australia's office building classes) or market rental rates. Such finer panel definitions would help reduce cost variation within each analysed group. Ideally each panel would include at least 30 observations to enable the use of more robust, parametric statistical tests.

With more observations future research can also attempt to determine whether or not particular delivery methods influence green building costs. For instance, several researchers have argued that by embracing integrative design, green buildings should cost *less* than conventional buildings. The use of such holistic approaches is referred to as 'tunnelling through the cost barrier' by Hawkins, Lovins, & Lovins (2010, pp. 113–124) who asserted that an integrative design process can produce enough energy savings that a building's costly mechanical system can be downsized or even eliminated, thereby more than offsetting the additional costs associated with the efficiency measures (*e.g.* double-glazing). Such claims could be verified if a sufficiently large dataset were gathered and information on each project's delivery method was available. Lastly, future research agendas can also investigate where cost premiums reside within a cost plan. Knowing which building elements tend to attract premiums, or savings, will allow these costs to be effectively addressed through cost management techniques and possibly through use of innovative project delivery methods such as integrative design.

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