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Cost-benefit prediction of green buildings: SWOT analysis of research methods and recent applications

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Abstract

In the literature, there is a great variation in the cost-benefits due to the differing methodologies used in the estimation. This study aims at presenting a literature review of cost-benefit prediction methods combined with a SWOT analysis, particularly emphasising data collection and analytical approach. Findings show that the methods used in green building cost-benefit studies can be grouped into different categories in terms of data collection and analytical approach. Each method has its advantages and disadvantages with divergent capabilities. This literature review revealed that much of the current cost-benefit research lacks validity and reliability, and has different degrees of bias.

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Keywords: Green cost-benefits; empirical surveys; simulations; meta-analysis; paired comparisons; unpaired comparisons; baselines and standards; SWOT analysis.

Nomenclature

SWOT	Strength, weakness, opportunity and threats
WLC	Whole life cycle
LEED	Leadership in Energy and Environmental Design
IAQ	Indoor air qualities
IEQ	Indoor environmental qualities

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1. Introduction

1.1. Background knowledge

In recent decades, there has been a growing concern regarding environmental issues, and consumption of energy and resources in the building sector. Green buildings or sustainable developments are a response to growing environmental concerns. Yudelson [1] defines green building as “A high-performance property that considers and reduces its impact on the environment and human health”. Yet, green architecture developments seem to encounter several impediments and barriers. Gou et al. [2] mentioned some of the major topics in green building market readiness and some cost-related barriers such as higher initial design and construction costs, extra costs of searching for green alternatives and certification processes, a long payback time of 20 years and a difficulty of defining quantifiable requirements during the procurement process. The extra costs and related risks of green design technology may discourage initial investors from commitment to green attributes [2]. Hwang and Tan [3] indicated that the ambiguity of the real costs and benefits is a major impediment to the development of green buildings.

Cost-benefit analysis is a quantitative economic analysis method which evaluates profitability and return of investments for alternative design options [4]. Similarly to traditional financial strategy and performance measurements, green cost-benefit studies examine the correlations between green strategies and green performances to discover relationships between costs and benefits for decision making. In green building studies, the relationships between green strategies and building performances are examined to verify the existence and strength of the link among certain variables, such as natural ventilation strategies and thermal comfort performances. Cost-benefit studies, though, aim to identify relationships among green costs as a consequence of green strategies and benefits as a consequence of green performances. In other words, the extra costs of green buildings are evaluated against the extra financial benefits. Figure 1 illustrates both the relationships between strategies and performances found in green research studies, and the relationships between costs and benefits resulted from cost-benefit research studies. An example of the mentioned relationship studies is the cost-benefit analysis of indoor environmental qualities (IEQ) and employee productivity [5-7]. The quality of working environments and comfort has a great influence on occupant productivity and well-being [8]. Higher employee productivity means higher financial benefits for companies [9]. Yet, monitoring and management of IEQ using sensor devices and other control strategies require purchases of equipment and higher building management fees. In a cost-benefit analysis, the extra costs are evaluated against the financial gains resulting from higher employee productivity.

In general, costs of green buildings can be divided into two categories: pre-construction costs and post-construction costs. Pre-construction costs include soft costs and hard costs. Soft costs are the costs related to design, commissioning, and documentation fees [10]. Hard costs are construction, materials, and building services costs [1]. Post-construction costs are building operating costs of energy consumption, water use, maintenance, and management. Benefits though, include differing savings and financial gains during building construction and post-construction phases such as higher property market value, higher rents, fewer vacancies, marketing opportunities resulting from social benefits, lower carbon taxes, higher energy savings, less sick leave, and higher productivity. However, it is important for a researcher to identify the link between interests of stakeholders and cost-benefit evaluations. Bordass [11] reported on the different interests of stakeholders with regard to cost variables during the whole life cycle (WLC) of green buildings. He indicated that for developers, who pay for land, design and construction costs, only the market value at the time of the project completion is important. In addition, green building labelling matters for developers, since it raises the marketing opportunities. Institutional investors, on the other hand, are interested in all cost variables except the running costs. However, Bordass also showed that many institutional investors care about energy savings to have longer leases and keep good tenants happy. For owner-occupiers, all the related costs are important, including the market value at the time of the purchase and in the future. Tenants, though, are only interested in running costs and benefits such as energy savings, maintenance and management costs, productivity, health and social benefits such as public relations. The interesting point here is that energy savings, health and productivity gains are not directly important for the initial investors. Overall, it could be said that the accumulation of diverse cost-benefit variables is imperative for a full package of economic evaluations, and that it should be communicated to various stakeholders in the green building industry.

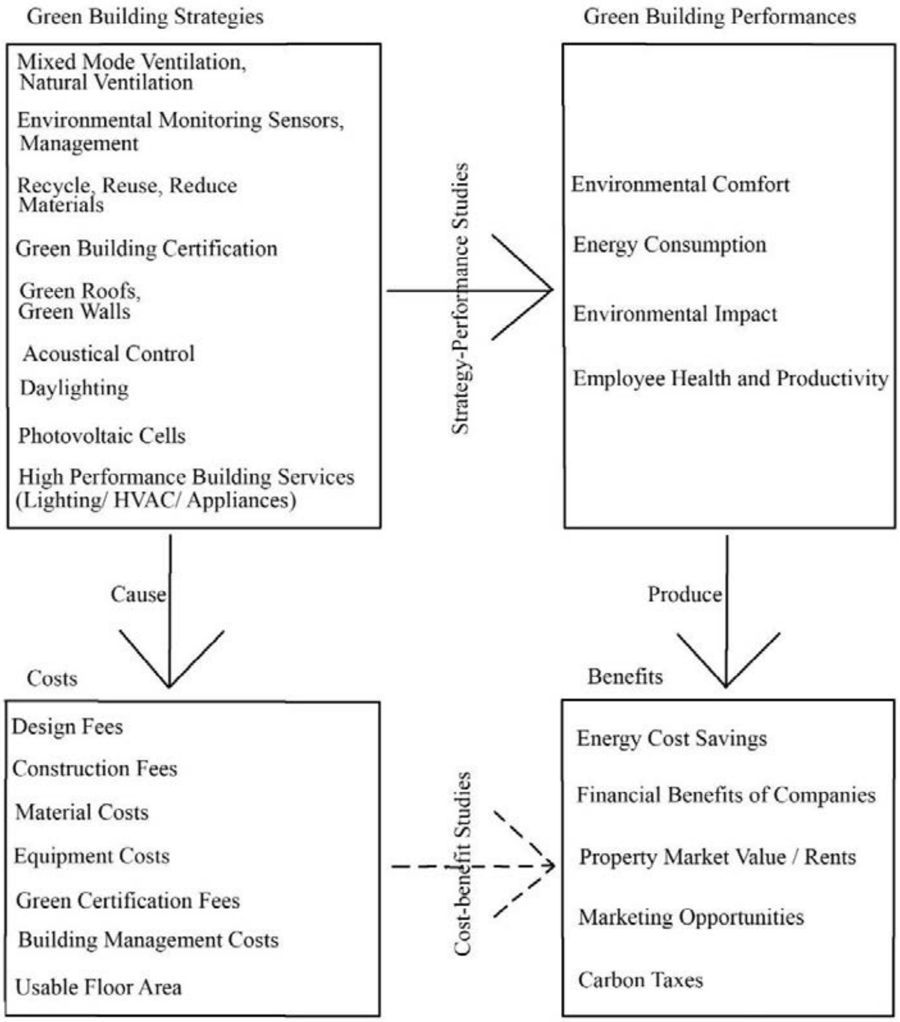

Fig.1. Flowchart of green cost-benefit methodology approach.

1.2. Aim of the study

In the literature concerning green cost-benefit studies, conflicting values were indicated for a number of green cost variables, notably for green cost premiums. The green cost premium is the cost difference between the green and non-green version of a project. Kats and Capital [12] indicated green cost premiums from 0.66% to 6.50% for Level 1 LEED Certified and Level 4 Platinum buildings respectively. In contrast, another research reported average cost premiums of 46% for green school buildings [13]. Productivity is another difficult factor to measure and evaluate due to the lack of well-defined metrics [14]. Similarly to green cost premiums, the ambiguity exists for the real productivity and health benefits of green buildings as Issa *et al.* [15] reported. The stated discrepancies seem to be related to the lack of systematic and clear methodologies for finding the real links between costs and benefits. The literature review showed that much of the current cost-benefit research lacked systematic and reliable methods for data collections and analytical approach. This research aims to review and analyse some of the existing study methods in order to raise some of the most common mistakes and obstacles in cost-benefit studies. This paper tries to provide a framework for researchers to evaluate strengths, weaknesses, opportunities and threats of each green building cost-benefit method before launching green building cost-benefit research projects. It has focused on providing an insight into the following aspects:

- The identification of some of the most common limitations and issues in cost-benefit studies.
- The understanding of the importance of cost-benefit study methodologies and their effects on research results and outcomes.
- The construction of a systematic framework for researchers to use during the methodology and research development process for evidence-based decisions.

2. Research methodology

The study was started by searching for key green cost study literature. The key words for the literature search were ‘green cost analysis’, ‘green cost-benefits’ and ‘green costs and financial benefits’. The purpose was to include the most validated and reliable sources in the review by referencing the highest cited publications including books, journal articles, reports, conference papers and grey literature. Although the reviewed papers were not inclusive of all available green cost-benefit literature, they indicated the trend in academic areas in green building cost studies by referring to the most cited papers. After the initial pilot study, five data collection methods and two analytical approaches were identified. Data collections included: 1) subjective studies, 2) objective studies, surveys, 3) surveys, 4) simulations and 5) meta-analysis. Analytical approaches were categorized into two groups of 1) unpaired building comparisons, and 2) paired building comparisons. SWOT analysis, which is an acronym of strengths, weaknesses, opportunities and threats, was used to systematically evaluate each methodology. The SWOT analytical tool was chosen due to practicality and simplicity of method assessments widely used in social sciences. Each method evaluation section starts with some basic descriptions and method characteristics followed by some examples and SWOT evaluations.

3. Framework 1-data collection methods

We reviewed literature comparing green building cost analysis methods used over the past decades. Two frameworks were used to categorize the methods. One was a data collection matrix, describing the ways in which data can be collected. The other framework was the analytical approach which is described in the following section (Section 4). Five major methods of data collection were identified from the literature including subjective studies, objective studies, surveys, simulations, and meta-analysis.

3.1. Subjective studies

This method investigates post-construction benefits. Subjective studies evaluate green building performance based on user perspectives [16, 17]. In cost studies, financial benefits are estimated through surveys among building users and occupiers. Participants score their productivity and well-being compared to another situation, such as before moving into a new building or after refurbishments.

Subjective studies were performed in research by Singh *et al*. [18]. Improved health and productivity was documented among office workers before and after moving into a platinum LEED rated building. Two case studies were analysed and both showed improvements in working hours of occupants and the reduction of absenteeism due to illness. Occupant surveys demonstrated improvements in wellbeing and productivity. Yet, a few limitations were observed in the study, such as the timeframe for reporting any dissatisfactions. Since normally, occupants are temporarily over-satisfied when moving to a new place, it is recommended that post-occupancy studies to be conducted at least one year after occupation to minimize the honeymoon hangover effect [19]. The other limitation of the study was that pre-move and post-move surveys were performed at different times of the year, which could have led to discrepancies caused by seasonal disease outbreaks.

The strength of the method is that direct measurements of cost benefits are evaluated through self-reported surveys rather than indirect measurements, which may be different from real values. The weakness though, is that subjective studies may represent biased values affected by perceptual beliefs and personal experiences. Occupant surveys are not usually capable of showing full subjective attributes. Research has shown that subjective and objective attributes may not reflect well-matched results as a result, a combination of subjective and objective studies is recommended [20]. The opportunity of the method is that it could be carried out in almost every type of green building, regardless of functionality and occupancy. As will be explained in the next section (section 3.2), for some types of working environments, objective studies of productivity measurements are extremely difficult or almost impossible. The threat is that the data collection process is time-consuming and demanding. As a result, many studies of this type limit the case studies to one or only a few buildings. Accordingly, generalizing conclusions from limited sample buildings may not be valid. Therefore, the method has a great amount of internal validity but no external validity for generalizations. This reduces the impact factor of research.

3.2. Objective studies

Similarly to subjective studies, objective studies explore post-construction costs and benefits. Cost data related to energy, productivity, health, maintenance and management could be verified through observations, documents and empirical studies. For instance, sick leave documentations or utility bills provide evidence-based details about health and energy use. The issue is that objective productivity is not easily measurable, especially for white collar employees, due to the lack of well-defined productivity metrics [14]. Notably, for management or professional service environments, it is difficult to define and identify to what degree higher productivity contributed to financial benefits. As a result, instead of direct measurements, indirect measurements may be used, such as absenteeism, working hours, safety rule violations, tardiness, the number of grievances filed and employee turnovers [21]. However, indirect measurements are less accurate than the direct measurements. For example, working hours may show how long employees stay at work, but does not exactly show how productively they performed. The duration of objective studies should be long enough (at least a year) to cover seasonal changes on variables such as seasonal epidemic viruses or outdoor temperatures. In objective studies, data collections are either undertaken by researchers, as mentioned above by analysing real-time building documents or from a secondary source such as building owners, architects, engineers, etc.

An example of empirical studies was demonstrated in a paper by Ries *et al.* [14], which studied the cost benefits of a company by evaluating the effects and improvements after moving into new facilities. In addition to employee surveys, for example, the amount of work performed by the blue collar workers was also measured to quantify productivity. However, for white collar workers, direct productivity improvements were not measured. For health and safety studies, workforce sickness absenteeism data was analysed to identify any patterns of change. Utility bills were normalised according to floor area and compared for water and energy saving analysis. For indoor environmental quality (IEQ), surveys were conducted pre-move and post-move into the new facilities. Results showed no noticeable changes in absenteeism and safety between employees. Productivity trends showed positive improvements in the new building. Yet, apart from green building features, other aspects of the new facilities may have influenced the increased productivity such as planning layout, equipment, interior design and many others. Accordingly, the research was inherently weak because of studying two totally differing buildings in terms of architectural properties other than green features.

The strength of the objective studies method is accuracy if case studies are based on empirical studies. The weakness may be the errors in indirect measurement of various factors. Yet the opportunity is that if subjective studies were conducted through validated case studies with accurate and reliable data collection methods, this would contribute to the creation of a valuable database. These types of databases are used to create benchmarks and verification of average values, which contribute to knowledge development of green building constructions. One threat of the method is that it is extremely time-consuming and most literature is limited to a few subjective case studies. Accordingly, confident conclusions could not be realized if only a single green building was studied.

If data is gathered from a secondary party, it might result in some degree of bias, since building owners may misreport costs due to public relations and commercial reasons. Accordingly, the validation of the data source is important for evaluating the reliability of results. Another issue with data collection from a secondary source is that because normally high-profile firms are open to sharing data and documentation with the public, the project pool represents only successful types of green buildings, rather than a diversity of green building types, some of which would be unsuccessful. Another threat of the secondary data collection methods is that since quoted values are from different resources, normalization of the data is necessary to avoid volatility; in fact values should be consistent in terms of inclusion of different costs such as taxes and design costs. Yet, this may result in manipulation of the data [11].

3.3. Surveys

Surveys in the form of interviews or questionnaires are conducted among professional groups such as practitioners, researchers, quantity surveyors, architects, or engineers about the costs of green buildings. It has been debated by many experts that the final outturns of green costs contrast with the predicted costs [15]. This research method reflects final cost outturns of buildings rather than preliminary estimates. The method of cost calculation is very different from other methods; as a result, it provides cost evaluations from a different perspective. Cross-examining professionals is one of the most common cost evaluation methods used by the public.

An example of this method is a survey study conducted by 'Building Design + Construction' magazine, which reported higher construction costs of green buildings [22]. According to the study, more than 41% of green buildings are more than 11% more expensive than similar conventional buildings. Issa *et al*. [15] conducted a survey to investigate practitioners' opinions about the real costs and financial benefits of green buildings. According to the research, practitioners identified high-cost green building premiums as the primary barrier to green building developments. Yet, the majority were uncertain about the financial benefits resulting from higher productivity and healthier environments in green buildings. Ahn and Pearce [23] also conducted a survey study among 87 companies which recruited graduates from three universities in construction programs. Another example of this method is a research by BRECSU [24], in which a survey was performed among surveyors and cost consultants. The article reported 5% to 15% higher costs for green buildings. Yet, by using this method benefits gained from increased productivity and better health have been underestimated by practitioners in the past [15, 24].

The strength of the method is that the final building costs from a practitioner's point of view, which is more likely to predict future of green building developments and commissioning, is examined. This provides an opportunity to see beyond researcher perspectives. The weakness of the methodology, though, is that it seeks opinions about the costs, and answers may have been biased by personal perceptions and experiences rather than hard evidence. It could also be said that many judgments are based on the publicized costs of showcase buildings. These specific types of buildings are normally over specified and expensive. As a result, most of these types of surveys reflected higher costs for green buildings [25, 26]. The opportunity is that a large sample population of surveys is possible. In literature, survey samples up to1200 participations were observed [15]. This means that large amount of data yield the opportunity of fewer statistical errors. Additionally, a diversity of cost indicators related to capital costs and running costs could be estimated through survey methods. This method also provides a relatively straightforward, easy and quick process for cost evaluations. The threat of the method is if the group of professional interviewees is not diverse enough, a biased response could affect the accuracy of the results. The other limitation of the method is that benefits caused by higher indoor qualities such as productivity and health benefits may be underestimated and not reflect reality.

3.4. Simulations

In simulation studies, buildings are modelled and standard rates of unit costs are applied to computer models or mathematical formulas which calculate materials, services and labour work required for the building. This method is especially beneficial for the estimation of individual green building features by building an identical pair of buildings, one with the specific green features and the other without. Simulated buildings could be also compared with data from real buildings in a paired building situation. In general, simulated results cannot be validated unless compared with other simulations or validated by real cost data. Although computer simulations are more popular for cost calculations, mathematical calculations were also used in the literature [27].

Davis Langdon [28] used computer simulations to compare the costs and benefits of 4, 5 and 6 Star Green Star buildings over a period from 2007 to 2030. Although the methodology and modelling processes were not well-defined, the paper provided comprehensive comparisons of benefits in a diversity of areas such as management, indoor environmental quality, energy, transport, water, material, land use and ecology, emissions and innovation. It was then indicated that jumping from 4 to 5 and from 5 to 6 Star Green Star comes with a price. Therefore, it was concluded that investing in green buildings requires social responsibilities. Another example was a work by GSA [29], which compared modelled costs of modernization of an office building with two options of green and conventional retrofit. Another research was focused on building a new federal courthouse with two options of green and conventional constructions. Both soft costs and construction costs of achieving LEED certifications were analysed. In both projects, two cost scenarios, low cost, and high cost, were developed for receiving three LEED certifications of Certified, Silver, and Gold. Energy modelling was performed with DOE-2 energy simulation software.

One of the strengths of this method is that a variety of variables including environmental attributes and whole life cycle (WLC) evaluations of buildings could be simulated and be utilised during the decision-making process. Particularly, payback time and green premiums can be easily estimated in this method. This type of cost analysis can be undertaken before the building is built, as well as for a whole life cycle. As a result, it can be used for cost evaluation and project budget allocations during the design development stage. One of the weaknesses of this technique is that tender prices may be different from the final costs. Accordingly, this method is just an estimate and not a definite pricing. Accordingly, this method is more suitable for a comparative study of different design alternatives, unless results are validated with real cost data. Another weakness of this method is that cost evaluation of productivity and health benefits cannot be estimated by computer simulations. Yet, energy savings can be estimated with this method, which can be utilised to compare different design options. Computer simulations provide a relatively quick and easy process compared with other methods such as statistical analysis. However, due to the possible complexity of computer modelling, special attention is imperative to ensure an accuracy of costs and energy estimations. The most difficult part is the estimation of unit rates [11]. National and regional averages and ranges of tender prices may be considered for more accurate estimation of unit rates.

3.5. Meta-analysis

Meta-analysis relies on one or several research papers for evaluating cost analysis. This method combines the findings of several studies to identify a pattern of relationships. Similarly to traditional narrative literature review, authors decide on the inclusion or exclusion of various pieces of literature in the review [30]. Traditionally, the criteria for literature selection are based on appropriate research methodology.

NEMC [10] used a single secondary source as a reference for each aspect of cost analysis including design, commissioning, LEED certification, energy modelling and construction of green features. For example, for design cost estimations, it referred to a research which claimed that building a green project adds 5% to the construction costs. It was also assumed that design costs are between 8% and 12% of construction costs. Thus, it was concluded that design costs of green buildings count for 0.4% to 0.6% of construction costs. Yet, it was not clear why it was assumed that design costs of green buildings follow the same pattern as traditional design costs. Another major limitation of this study, however, was that it relied on single research in each of the subject areas. The selection criteria for the secondary source were not well executed in the paper. A similar analysis method was used in a research by Bianchini and Hewage [31] to estimate the probabilities of the social cost benefits of three types of green roofs. For life cycle analysis, Monte Carlo simulations were utilised to estimate the probabilities. Yet, this study had the same limitation as the previous research in relying on single research for promoting conclusions. Much of the referenced research was based on social cost benefits of parks, and the judgements of green roof benefits were based on the assumption that green roofs were similar to parks with lower social benefits. The study had a considerable number of unexplained assumptions in terms of the social impacts of green roofs in comparison with parks.

A good example of validated meta-analysis was utilised by a group of researchers for developing a web-based building investment decision support tool (BIDS^{TM}) [32]. The tool provides support and consultation for evidence-based decision making based on a database of case studies showing correlations between building environmental qualities and cost-benefit factors. The study is based on several case study projects in different subject areas around the world such as temperature control, air quality, lighting control and access to the natural environment, and how these factors influence occupant productivity and health. The case study selection was based on the statistical significance of the results, and also on the fact that among approximately every one thousand reviewed articles only one was included in the database.

The strength of the method is that it makes use of the available research; in fact less time is wasted for data collection compared to case study approach. Meta-analysis quickly goes to the analysis phase. One of the biggest challenges in cost studies is the availability of data. Therefore, this method of revising other papers, refers to a much larger sample of cost data, and research is less restricted by data availability. The weakness of the method is that the validity of the research depends on the reliability of the secondary papers. Another issue with reliance on secondary research is the lack of consistency in giving information and building data. For instance, a researcher should be informed about whether tax costs or green certification expenses are included in the final quoted costs. One of the opportunities of the method is that, as a literature review technique, meta-analytic studies provide foundations for evidence-based professional practice, and more importantly for the construction of theories. This method seeks empirical evidence for building a hypothesis for future research. The threat is that conflicting findings found in numerous works of literature may cause confusion, as some papers may report significant correlations between variables and some may reflect no relationships. Additionally, like statistical methods, normalization of the data is imperative in the meta-analysis, which again may cause the manipulation of data. Mills *et al.* [33] performed a meta-analysis and used the McGraw Hill Construction Cost Index to normalize data for inflation rates. The other threat is that relying on a single source of research may lead to the production of false results.

4. Framework 2-analytical approach

The analytical approach framework categorises literature based on analysing data and generating conclusions. Based on this framework, papers fall into two broad classes; 1) unpaired building comparisons, and 2) paired building comparisons.

4.1. Unpaired building comparisons

Unpaired building comparisons, as a statistical analysis methodology, are based on a comparison of actual costs of unpaired green buildings and conventional buildings to predict cost benefits and statistical probabilities. Buildings in a database are categorized into various groups based on building features such as scale, functionality, green building certification, design, and sustainability goals in a way that any given building could be defined in a group. The number of case studies in green groups and conventional counterparts may not be necessarily equal. This method has been used in a number of highly cited pieces of research in cost analysis studies [34]. Comparative analysis may also be performed by comparing results with baselines and national standards [35, 36]. Yet, the availability of baselines is a deterministic factor for method feasibilities.

Davis Langdon Publications have produced a series of articles in which the unpaired building comparison method was examined [37, 38]. These articles gathered cost data from a total of 83 green buildings and 138 non-green projects. The studied buildings were categorized into five groups of academic buildings, laboratories, libraries, community centres, and ambulatory care facilities. No significant correlations were found between the LEED certification degree and the costs in the rest of the building typologies. One of the limitations of the study was that in some of the categories such as the community centre and the ambulatory care facilities sample sizes were very small (18 and 17 respectively) and developing statistical analysis was infeasible. Another example of statistical analysis is the research by Shrestha and Pushpala [13]. The study compared the costs of thirty green school building with thirty non-green school buildings built by the Clark County School District in Nevada. The study stated that construction costs and project durations of green buildings are outstandingly higher than non-green projects by 46%. One of the weaknesses of this research was that the data sample was limited to a specific developer, which seemed to construct only a more expensive green building type.

Comparisons with baselines were observed in several research studies by Kats, which are among the most cited and referenced cost analysis research [35, 39, 40]. In a research, detailed information about 170 green buildings was included and used as a comparison tool for estimating green building cost-benefits [35]. The values were compared with a baseline of the Government's national survey reports of water consumptions, emissions and ASHRAE 90.1 for energy. Data included the green cost premiums, energy, and water saving, and health and productivity benefits. The research showed that green buildings cost only 2% more than conventional buildings in the US, and the average payback time for a green building was predicted to be six years. One of the weaknesses of this report was that the data reflected projected performance and not the actual performance measurements, including energy data. Most data was provided by architects, building owners and developers, including energy savings and green building premiums. Post-occupancy studies have proved that many buildings do not meet their design objectives of the energy goals claimed by designers and architects. As a result, this report presented a better image of green building performance.

The strength of the method is that large database collection is practical due to the fact that it is less time-consuming, and may lead to minimized statistical errors. To increase the validity of analytical approach it is imperative that a diversity of building types to be included in the analysis, at least 30 in each group [41]. One of the biggest weaknesses in unpaired building comparisons is the cost variance among the existing green building stock. Showcase buildings normally stand at the top of the range, since green design features are normally over-specified and result in higher costs, especially if Photovoltaic panels are introduced into the design. Accordingly, there is a possibility that no significant correlations, as well as false correlations between variables could be observed in the case of errors in data collection methods. The unpaired building comparison method, though, provides an opportunity to study correlations between specific design features and costs. The threat of the method is that classifications of buildings into appropriate groups based on building characteristics or standards should be placed with precise accuracy. Background and real-time information should be used to logically validate classifications. Comparisons with baselines could be resource intensive, since the outcome of the research depends on the availability of data in each study group or national benchmark.

4.2. Paired building comparisons

This method compares cost benefits between green buildings and conventional counterparts. In comparison with unpaired building comparisons, this method provides a more systematic and structured analysis for controlling other influencing factors on costs. Paired building comparisons collate data from two identical buildings or retrofitted building before and after the work. It is widely used for cost analysis of comparing health and productivity benefits in pre and post green retrofitting or among workers pre and post move into a green building. Depending on the availability of case studies, this method can be used for cost evaluation of specific green building features, for example, green roofs or natural ventilation systems. The data collection method could be either a simulation [42-44] or a real-life building experiment [14, 18].

Another type of this analytical approach compares the actual costs of a group of buildings with paired computer models. Green buildings may be in either the actual cost or the modelled group. It could be said that this type of research is less restricted by the availability of data, since computer modelling is subject to the availability of building drawings and construction specifications. Accordingly, a wider range of green building typologies can be studied with this method, compared with statistical analysis. An example of this was found in research by Rehm and Ade [41], which focused on the construction costs of green buildings. Here, seventeen green office buildings were paired with a set of modelled buildings. The buildings were categorized into five panels for comparative study, the whole dataset, mid-rise, high-rise, 4 Green Star, and 5 and 6 Green Star buildings. The paper demonstrated that the average costs of green buildings were higher than those of paired buildings, but there were a considerable number of green buildings which had lower costs compared to modelled costs. It was then discussed that the cost variances in the dataset showed heterogeneity of building performances and costs. As a result, it was recommended that larger sample sizes be studied for enabling parametric statistical tests.

The strength of the study is controlling variables by studying identical buildings. Unlike unpaired building comparisons, extensive statistical variations among different green building types no longer exist. The weakness, however, is that the method is resource intensive and the chance of finding a case with specific requirements is small if real buildings are studied. Yet, simulation methods could be very time-consuming, and all studies of this type had only one or two case studies, which again resulted in statistical errors due to small sample populations. The opportunity in this method is a production of validated case studies which may lead to the formation of a valuable database for cost comparisons. The threat of the method is the validation of generalizations. The paired studied buildings represent only a single design and building characteristics which may be influenced by many contextual and non-contextual factors. Therefore, large sample of case study buildings is imperative to validate generalizations and parametric statistical tests.

5. Discussions and issues for future cost studies

It could be concluded that a wide range of green cost variables is required to further expand developments and commissioning of green buildings worldwide. Based on the SWOT analysis, the reviewed methods in this paper demonstrated various strengths, weaknesses, opportunities and threats in demonstrating certain variables. The reviewed methods provided good analytic techniques for estimating different aspects of cost variables. Yet, some of them were more reliable and practical for estimating specific cost values such as green cost premiums or productivity and health benefits. Accordingly, before launching any cost analysis, it is imperative for researchers to identify the audiences for the research and the types of cost data which matter to them.

Quantifying the benefits gained from higher indoor qualities are extremely challenging, but have a huge influence on the success and financial outcomes of companies [45]. Subjective studies are validated more for health and productivity benefits of green building than any other cost factors. Objective studies proved to be a complementary study to subjective surveys for full running costs estimations. For theory and hypothesis formations, meta-analysis proved to be the best option as it overviews a large database of past research and background knowledge by referring to secondary sources. The meta-analysis method is less time-consuming than other methods and can quickly go to the analysis phase of cost studies.

Surveys of professional groups provide a vision of future trends and open up a new perspective from a practitioner's point of view if carried out among professionals in the industry. However, survey studies reflected the most contradicting findings compared to other papers performed by academic researchers. The results of these papers reflected the higher costs of green buildings. The most important factor, though, is that large sample sizes are collected, and from a diversity of expert groups. Simulations, though provide analysis opportunities with wider cost indicators, especially with computer modelling techniques for instance WLC, but could be demanding and extremely time-consuming. In terms of the analytical approach, paired building comparisons provided more validated results by calibrating other influencing variables. Yet, the approach is restricted by the availability of paired building data and the demanding aspect of simulation studies. Unpaired building comparisons may reflect less validated correlations between variables due to the heterogeneity of building costs. In this approach, a large database population is recommended for generalization of findings.

Many of the available research studies were collected data from building owners or architects and not from empirical studies. Many of these studies suffered from the validity of source data and represented a better image of green buildings with low costs and higher benefits. Yet, it is important that data collections are based on empirical studies in the form of subjective and objective evaluations. However, these types of detailed data collection methods are extremely time-consuming and could be expensive. Accordingly, works of Loftness *et al.* [32] for example, by gathering data from hundreds of empirical case studies, are of a great value and could significantly contribute to the production of validated cost studies.

6. Conclusion

Green architecture suffers from a lack of quantitative cost-benefit studies to accelerate their application and use. Unfortunately, the lack of clear and systematic research studies of building costs have resulted in the ambiguity of green building cost-benefits. This research aimed to draw attention to the importance of research methodologies and compared advantages and disadvantages of each method for calculation of different cost variables. This research reviewed only the mainstream methods for green cost-benefit predictions. The reviewed papers are inclusive of the most validated research works in the field, but not exclusive to quantitatively comparing the applications of different methods. A systematic quantitative literature review [46] is then recommended as future studies for further investigations and explorations of existing methods.

Empirical experiences based on objective and subjective studies in real buildings have the benefit of experimental controls and internal validity of research design. However, the production of such detailed and accurate cost-benefit data is a demanding and time-consuming process. In addition, many contextual and non-contextual factors influence the cost-benefits of green buildings, which means the generalisation of findings based on a few building cost performances is not externally validated. Data collection from a secondary source, by being less time-consuming and demanding, have the benefit of larger sample collection possibilities and enhancing external validity. Yet, attention should be paid to data collections from reliable and trusted sources to avoid the production of false results. Accordingly, a balance between the validity of data sources and data sample sizes is necessary to minimize sampling errors and enable parametric statistical tests. It is then recommended that tools like BIDS [32], which is a tool based on the meta-analysis of several trusted and empirical studies, to be developed to accumulate the production of the large sample pool of validated database. The most common limitations and issues found in green cost-benefit literature could be summarised as:

- Restriction of database and case studies to the availability of data and reflecting only specific types of green buildings.
- Lack of consistency in data collection methods.
- Unreliable sources for data collection, which may result in biased research outcomes.
- Generalization of findings based on few case studies and building cost performances.
- Difficulty of demanding empirical studies (subjective and objective).
- Lack of sophisticated categorization of green building types and reflecting the heterogeneity of green building costs, which may result in finding false correlations between variables.
- Normalization of data if gathered from various sources to minimize data collection errors.

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