Developing an Assessment System on Green Construction Sites in Australia

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Abstract:
Around the world, there are many assessment systems for green building, such as the LEED system in America and the BREEAM system in the U.K. In Australia, the Green Star rating system is widely considered the standard for assessing healthy, resilient, positive buildings and places. However, these assessment systems are generally limited to new buildings from life-cycle viewpoints, and are less focused on environmental sustainability assessment at construction sites. Moreover, few countries have published green assessment systems for construction projects. How to assess and improve the environmental sustainability of projects during the on-site construction stage plays an important role in enhancing the sustainable performance of construction companies and products. This study will develop an assessment framework for rating green construction projects during the on-site stage. An extensive literature review was first conducted to develop the framework based on identifying the relevant system and indicators of green construction practices. The developed framework will be further tested and improved through the Expert Evaluation method. Therefore, the framework could be used to assess green construction practices and provide education resources for construction managers, engineers, academics, students and workers to improve their awareness and abilities in promoting green construction in Australia.

Keywords:
Assessment, Australia, Construction Site, Environmental Performance, Green Construction.

1 Introduction

Environmental problems have become a serious global issue, particularly in the building and construction industry. The building and construction sector in the world contributes 36% and 37% to global final energy consumption and energy-related CO_2 emissions, separately (United Nations Environment Programme (UNEP), 2021). More importantly, construction activities have negative impacts on natural habitats and the natural behaviour of wildlife. For example, construction activities have serious effects on terrestrial and aquatic flora and fauna, such as 'clearing of native vegetation (including habitat); works around and within watercourses; noise, vibration and light impacts; disturbance of soils, consequential erosion and the mobilisation of sediment; use of chemicals/fuels (potential for spills)' (NSW Government Transport Roads & Maritime Services, 2017). According to the fact sheet from World Wildlife Fund in 2017, the problem of impacting habitats and wildlife from human activities in Australia is exceptionally severe, such that more mammal species have been lost more than in all other continents combined in the past two centuries. More importantly, human error activities can also impact the environment negatively during construction. Due to the complexity of building and the long-term process of building construction, human errors are not uncommon in different building components and construction stages due to a wide range of reasons, which can contribute to more energy and material consumption, but also cause more greenhouse gas (GHG) emissions and waste. Therefore, the negative effects need to be controlled to achieve environmental sustainability in the construction industry.

In order to solve the environmental problems in the building and construction industry, the concept of green buildings (sometimes called sustainable buildings) has been developed in theoretical and practical research. Green buildings are designed to meet the needs of residents with very low or even zero GHG emissions. Furthermore, in order to promote the implementation of green buildings, various stakeholders have been always searching for certification systems that prove the ecological approach used in new buildings (Freitas and Zhang, 2018). For example, one of the world's leading certification systems for rating Green Building is BREEAM (standing for stands for Building Research Establishment Environmental Assessment Method) which is the first to be established in the UK. The rating systems as assessment tools were also established depending on each country's needs such as the LEED (standing for Leadership in Energy and Environmental Design) system in the U.S., the Assessment Standard for Green Building in China, and the Comprehensive Assessment System for Built Environment Efficiency in Japan. However, green buildings have not been widely and properly explored by the building and construction industry, government, and civil society researchers (Melchert, 2007). Particularly, these certification systems are generally focusing on rating the green performance of buildings in the design and usage stages and obscuring their green performance during the construction stage on construction sites. For example, Khanna et al. (2014) have indicated that China's rating system is mainly concerned with energy efficiency integrations such as HVAC design, heat pump systems, using solar energy and natural lighting. Accordingly, this study aims to develop an evaluation framework for green construction sites by employing a series of research methods and expert verification.

2 Literature Review

2.1 The Conception of Green Construction

The Green Construction Guideline issued by MOC defined 'On the premise of ensuring quality, safety and other basic requirements, scientific management and technological progress should be used in engineering construction, to maximise the conservation of resources and reduce the construction activities which will bring negative impacts on the environmental, and to achieve the goal of four savings (energy, land, water and materials) and environmental protection' (Shi, et al., 2013). Green construction can benefit to find solutions to diminish the consumption of energy resources, materials, and land during the construction phase of projects. Cole (2000) pointed out that good green construction practices can improve construction cost efficiency and productivity and benefit environmental, social, and economic performance. The significance of implementing green construction embodies reducing energy and water consumption; decreasing emissions and pollution; improving waste recycling; using low-carbon, recyclable and renewable materials; and minimising construction activity impacts on ecosystems and wildlife. For example, green construction practices in Australia require waste disposal actions such as avoiding, reducing, reusing, and recycling (Park and Tucker 2017). Therefore, promoting green construction practices can support environment recovery, improve material usage efficiency, and benefit climate change mitigation objectives.

It is noted that the concept of green construction is different from green building, which is generally evaluated from an environmental perspective during a building life cycle, whereas green construction is evaluated for buildings during a construction stage. More importantly, the concept of green construction can be used for other kinds of construction projects, such as industrial and infrastructure projects. Besides, there are structural differences between the concepts of sustainable construction and green construction, although sometimes they can be interchangeably used in practice (Owusu-Manu et al., 2022). Green construction is evaluated from environmental and social perspectives but mainly on environmental aspects, however, sustainable construction shall be assessed through all the three pillars of sustainable development — environmental, social, and economic sustainability (Susanti et al., 2019).

2.2 Green Construction Assessment

As more and more countries, entities, and persons are aware of the importance and requirements of sustainable development, environmental management is widely implemented and studied by practices and researchers, such as the United Nations Environment Programme. Environmental assessment is a tool to evaluate environmental performance for different business sectors, which can provide reliable, objective and verifiable results to manage organisations' environmental objectives and achievements, check the satisfaction and compliance relating to environmental protection regulations, and forecast the future trend of environmental development and then formulate suitable environmental strategies (Tam et al., 2004). In the global building and construction sector, there are approximately 40 systems to assess and/or rate the environmental performance of buildings and construction projects (Thaickavil and Thomas, 2019). However, these assessment and rating systems are generally to evaluate the environmental performance of buildings through a life-cycle viewpoint. For instance, according to the Green Building Council of Australia, the assessment categories of Green Star consist of management, indoor environmental quality, energy use, transport, water, materials, land use and ecology, emissions, and innovation. Besides, there are very few rating systems focusing on green construction sites.

Previous studies have tried to develop a framework to assess green construction performance from different perspectives. Cole (2000) investigated building environmental assessment methods to assess construction environmental performance from resource use, ecological loading, and health impacts associated with building production and operation. Tam et al., (2004) proposed a system called 'green construction assessment' to assess green construction consisting of six environmental management indicators of management involvement, training, investment, environmental management programme, research and development and environmental planning; and seven operational performance indicators of maintenance of equipment, air pollution control, noise pollution control, water pollution control, waste pollution control, ecological impact, and energy consumption. Li and Luo (2011) established a framework for rating green construction through three themes including energy and resource conservation, reduction of environmental impact, and on-site construction supervision. Moreover, Zhou et al. (2013) developed a sustainability assessment framework encompassing environmental, economic, social, and technical aspects through the life cycle of the procurement process. In order to enhance a green construction operation, Zou and Moon (2014) evaluated the environmental performance of on-site construction through the categories of the ecosystem, natural resources, and human health. To quantitatively assess the sustainable green performance of ongoing construction projects, Firmawan et al. (2016) introduced the green construction site index by measuring an efficiency index, productivity index and awareness index. Furthermore, in order to identify the gaps between the awareness and activities on green construction in China, Zhou et al. (2018) evaluated green construction from an on-site personnel viewpoint including the categories of environmental protection, material saving, water saving, energy saving, and sustainable land use. Recently, to assess and link green construction and environmental performance, the level of significance of environmental performance is assessed using the indicators of air quality, water, and sanitation (Owusu-Manu et al., 2022). In summary, different studies generally develop different evaluation and rate systems including various categories and indicators based on their specific requirements and objectives. Therefore, it is necessary to further investigate an evaluation framework for green construction sites, particularly in the Australian construction domain.

2.3 The Requirements of Green Construction in Australia

Australia is considered one of the highest GHG emitters in the world, as Australia's per capita GHG emissions are very high. Furthermore, Australia, as a signatory to the Paris Climate Agreement, has committed to reducing GHG emissions to under 43 per cent of 2005 levels by 2030 and to achieve net-zero emissions by 2050 (Climate Action Tracker, 2022). In Australia, one of the key emitters is the construction industry, as approximately 25% of the nation's annual GHG emissions were consumed in building construction, operation, and maintenance (Martek and Hosseini, 2019). For example, according to the calculated results from the data of the Australian Government Department of Industry, Science, Energy and Resources, GHG emissions in the NSW construction industry have increased by 2.8% annually from 2004 to 2018. Accordingly, it is very necessary to study the GHG reduction pathways in the Australian construction industry to contribute to the Australian commitment to GHG reduction targets.

Australia is also recognised as a leader in developing and applying green construction schemes to reduce the environmental impact of construction activities. For example, Australia has effective waste management codes, regulations, and waste reduction projects in different regions, e.g., ACT promotion of on-site waste re-use and the Waste Authority in Western Australia (Li and Du 2015). There are two programmes related to green construction in the Australian construction area, including the Green Star rating system and the Infrastructure Sustainable rating system. The Green Star rating system was published by the Green Building Council of Australia in 2003 and has been internationally acknowledged as a sustainability rating and certification system. The system consists of four rating tools for certificating building design and construction, operation, fitouts and communities, named Communities, Design and As-Built, Interiors and Performance. Moreover, the Infrastructure Sustainability system was established by the Infrastructure Sustainability Council of Australia (ISCA) in 2007, which is a voluntary rating system to promote resource efficiency, waste reduction, and cost savings in infrastructure projects. However, policies and regulations in Australia mainly focus on the immediate GHG emissions released from operating the building and paid no attention to the gases released from the construction process (Yu et al., 2017). For example, the *Green Star* rating system is mainly a tool for performance prediction during building planning and design (Martek and Hosseini 2018), focuses on energy use (building operations after construction) and indoor environmental quality (Doan et al. 2016), and mostly assesses building performance after the building is built (Tuohy and Murphy 2012). There has been little research to examine the extent to which the adoption of green construction programs in achieving the advantages outlined under the main Australian Green Construction schemes (Shooshtarian et al., 2019). Therefore, it is necessary to develop a rating system to systematically focus on evaluating the environmental performance of Australia's construction sites while a project is being built.

3 Research Methodology

The research method of this study includes four steps which are presented in Figure 1. The first step is to develop a rough framework for assessing green construction sites by using brainstorming methods among all authors through several meeting discussions and improvements. The developed rough framework could provide directions, instructions, and structure classifications for the following steps. Secondly, the scientometric literature review and content analysis are used to review the literature on green construction. The database is based on Scopus as the citation database due to its more comprehensive coverage compared to the other databases. The literature search strategy is (TITLE-ABS-KEY ("green construction”) OR TITLE-ABS-KEY ("sustainable construction”) AND TITLE-ABS-KEY (rating) OR TITLE-ABS-KEY (assessment) OR TITLE-ABS-KEY (evaluation) OR TITLE-ABS-KEY (framework)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (LANGUAGE, "English")).

The initial search identified 890 publications. Subsequently, the title and abstract of articles were manually analysed to look for publications related to evaluating green construction on the project site level, where 112 articles were initially selected. As this study focuses on establishing a framework/system to systemically assess green project sites during the construction stage, most publications that partly assess green construction are neglected. Finally, only 26 journal papers are selected to be emphatically analysed. Due to the length limitation of the paper, Table 1 only shows the key journal papers which have developed a framework to assess green performance for construction sites. Consequently, the indicators which have been used to assess green construction sites are identified by summarising these identified papers. Thirdly, the research will critically compare and analyse these indicators and then improve the rough framework into a formal draft. Finally, the developed framework will be further verified and improved by using an expert evaluation method mainly through email commutation. 6 professionals in the construction management areas were emailed, and 3 of them presented their viewpoints on the evaluation framework and indicators.

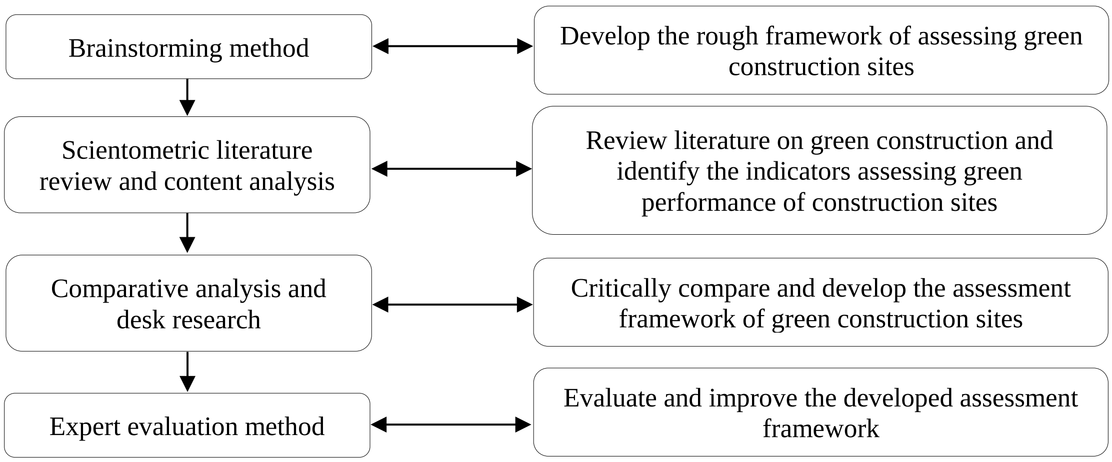

Figure 1. Research methodology

4 Findings and Discussion

4.1 Key Indicators of Assessing Green Construction

By implementing the first two steps of the research method, previous key studies which had attempted to develop rating systems for evaluating green construction are identified in Table 1. It can be concluded that the rating indicators which are widely employed to assess the performance of green construction consist of construction materials, site waste, site protection and energy consumption. Although the BREEAM, LEED, and Green Star rating systems include all environmental factors to assess green building performance, they pay more attention to evaluating building performance during the operation and maintenance stage, instead of during the construction stage. For example, in the LEED rating system, the energy consumption and GHG emissions of kitchen equipment are measured, not of excavation equipment. Besides, it is understandable that these rating systems do not consider social factors as credit points, as they only assess building environmental performance.

Table 1 shows the assessment indicators used in these academic studies. First, construction materials, site waste, site protection, and energy consumption are the common indicators, although different studies have different measurement scopes. Material and energy resources are consumed on construction sites due to various construction activities such as site preparation, demolition, assembling, altering, installing, and clearing, which could directly affect the environment. Demolition and construction waste is another crucial matter to affect the environmental performance of construction sites. For example, according to the Australian Bureau of Statistics in 2018, 33% of construction waste ends up in landfill which could reduce air quality, destruct soil structures, and risk fire and water pollution. Construction sites have a negative impact on natural habitats and the natural behaviour of wildlife. For instance, construction noise can cause alteration in feeding and breeding patterns, which is detrimental to the surrounding flora and fauna. Second, the indicator of missions is another direct important factor affecting green construction. It is not only related to energy consumption, but embodied carbon emissions of buildings are a negative and significant effect on improving construction environmental performance due to huge consumptions of building materials. For example, Huang et al. (2018) pointed out that 94% of the total emissions of the construction sector are indirect emissions by measuring GHG emissions related to energy-use in the whole world. Third, site management in the environment shall be considered in evaluating the green performance of construction sites, as it will indirectly affect the environment by controlling the construction activities of workers. Their awareness and ability in protecting the environment during construction will affect green construction practices. Fourth, introducing green construction innovation as an evaluation indicator is an efficient pathway to promote green construction practices. Finally, the social factors shall be considered to assess green construction sites, as construction activities can affect the surroundings such as producing lots of noise, dust, and traffic jams. Therefore, these indicators shall be included in the evaluation framework as they affect the environmental performance of construction on sites.

Table 1. Key indicators of assessing green construction used in previous studies

	BREEAM	LEED	Green star	(Cole 2000)	(Tam et al., 2004)	(Li and Luo, 2011)	(Zhou et al., 2013)	(Zou and Moon, 2014)	(Firmawan et al., 2016)	(Zhou et al., 2018)	(Owusu-Manu et al., 2022)
Construction materials	√	√	√	√	√	√	√	√	√	√	√
Site protection	√	√	√	√	√	√	√	√	√	√	√
Site waste	√	√	√	√	√	√	√	√	√	√	√
Energy consumption	√	√	√	√	√	√	√	√	-	√	√
Emissions	√	√	√	√	-	-	-	√	-	√	√
Site management	√	√	√	√	√	√	-	-	-		-
Green construction innovation	√	√	√	-	-	-	√	-	-	-	-
Social responsibility	-	-	-	√	-	√	√	√	-	-	-

4.2 Framework for Assessing Green Construction on Sites

By implementing the last two steps of the research method, the final framework for assessing green construction on sites was developed in Table 2. After the verification of expert evaluation, the concept of emissions will not be considered as a theme, as it is mainly related to energy consumption and the air quality indicator is located in the theme of Site Protection. The framework consists of seven themes: construction materials with five indicators, site protection with seven indicators, waste management with five indicators, energy consumption with four indicators, site management with three indicators, green construction innovation with three indicators, and social responsibility with four indicators. Accordingly, the total 31 indicators are identified and developed on the basis of literature review and expert verification.

During the evaluation of green construction, the theme of construction materials needs to consider green procurement where the procurement process and products are green. For instance, material procurement gives high priority to the local product market, and optimises the procurement plan aiming for zero inventory, which could reduce GHG emissions. Moreover, green construction materials are encouraged to be utilised, for example, which are made from renewable sources, easy to recycle, and have a long-life span that can lower the chances of multiple maintenance procedures. Controlling material and water usage in construction is also crucial to improve usage efficiency, decrease waste and cost, and reduce GHG emissions, such as adopting water-saving and water recycling devices. Particularly, toxic materials shall be voided, e.g., Asbestos, Chemicals, Batteries, Solvents, Pesticides, and Oils.

Table 2. Framework for assessing green construction on sites

Theme	Indicator
Construction materials	Green procurement
	Green materials used
	Control material usage
	Control water consumption
	Control toxic materials
Site protection	Demolition management/site preparation
	Landscape protection
	Pollution control
	Level of vibration&noise&light control
	Level of air quality/temperature/dust/humidity control
	Level of groundwater protection
	Eco-efficiency level of construction site layout
Waste management	Construction waste generation ratio
	Waste reuse&recycle ratio
	Waste disposal (landfill) ratio
	Wastewater treatment/reuse rate
	Control hazardous waste
Energy consumption	Total energy consumption ratio
	Renewable energy consumption ratio
	Fossil fuel consumption ratio
	Clean-energy and energy-efficient equipment used
Site management	Green construction objectives, planning, and management implementation
	Green construction management organisation and accountability
	Green construction training and awareness
Green construction innovation	Clean construction technologies/methods applied
	Level of off-site manufacture
	Level of promoting green construction innovation
Social responsibility	Local community contributions
	Neighbourhood disturbance
	Public traffic disruptions
	Worker's health and safety

Site protection in green construction is to preserve the land of construction sites and surroundings by protecting the natural original landscape, for instance, to keep soil, trees vegetation, and biodiversity during demolition and site preparation; to diminish the degree of landscape damage, stormwater damage and topsoil erosion during construction; to improve eco-efficiency of the construction site layout by arranging the site layout compactly and making site loading reasonably; to control pollutions spreading to the land, water and air; to reduce the linkage of vibration, noise and light; and to ensure air quality by controlling air dust, temperature, and humidity; to protect groundwater by avoiding dumping and contamination. Besides, building construction education programs can impact this significantly through enhancing education resources. Indeed, this is the easiest one for them to address.

Waste management is the management of construction waste produced from, for instance, assembling and disassembling of building materials on site, disposal of waste and transportation to landfill, and demolition and renovation work. The efficiency and effectiveness of waste management activities can be measured through these indicators of the construction waste generation ratio, waste disposal ratio, waste reuse and recycle ratio, and wastewater treatment and reuse rate. The measurement results can provide efficient useful information and compare these waste management activities, benchmark the best waste management sites, and then identify the aspects and pathways to improve waste management performance. Particularly, hazardous construction waste must be managed completely.

Energy consumption during construction is crucial as it can directly affect the environmental performance of construction sites. Energy consumed during construction is mostly about the transportation and operation of construction equipment such as backhoe loaders, dampers, cranes, and hydraulic excavators. Besides, the energy consumed to generate electricity and to use facilities for natural light and ventilation shall also be considered in evaluating green construction. Accordingly, the total energy consumption ratio, renewable energy consumption ratio, and fossil fuel consumption ratio are separately measured to investigate and compare the different performances in energy consumption. Clean-energy and energy-efficient equipment are encouraged to be used on sites.

Site management is an indicator to evaluate whether there are management planning, organisation and persons, accountability, measures, and objectives for green construction on sites. It is mainly to evaluate whether this management has been documented and implemented efficiently and effectively. The management process focuses on the whole construction processes on sites, from setting out and preparing the site, procurement, transporting building materials to the site, construction, and post-construction. Besides, it is recommended to offer green construction knowledge training for all stakeholders who are involved on construction sites (e.g., engineers, builders, contractors, subcontractors, and construction workers). The awareness and abilities of the stakeholders on green construction could be checked and improved by a series of testing and questionnaire.

Green construction innovation and application can significantly enhance the environmental performance of construction sites. Green construction innovation is to use and apply clean construction technologies and methods with less energy and material consumption, such as technologies to manage wastewater, solar energy for lighting and electricity on site, and smart construction machines and equipment. For example, off-site manufacture (e.g., modular structures) and prefabricated construction are encouraged, so that construction sites are without heavy construction activities. Lean construction is also an innovative construction method to reduce the cost, energy, material, and time consumption of construction processes.

Social responsibility in green construction is to take measures and activities that obligate social responsibilities during construction such as avoiding neighbourhood disturbances and public traffic disruptions, and caring about workers' health and safety. It is widely noted that construction activities may produce inconveniences for the surroundings, such as power outages, waste, noise, vibration, parking, and traffic restrictions. Moreover, the health of the workers, staff and the public influenced by construction shall be considered as an indicator to evaluate green construction, due to its significance for sustainability. Contributions to the local community could add credit points to rate the green construction performance, such as doing some volunteer work for the local community.

5 Conclusion and Further Research

The current green building rating system generally and mainly evaluate building performance from a building life cycle. It is necessary to investigate and assess green construction performance for buildings during the construction stage. This study employed a systematic literature review and an expert verification method to develop a framework to evaluate green construction on sites. Previous studies had explored various evaluation systems and indicators. These indicators are normally related to construction materials, site protection, site waste, energy consumption, emissions, site management, green construction innovation, and social responsibility. Accordingly, the evaluation systems were developed, including the seven themes of construction materials, site protection, site waste, energy consumption, site management, green construction innovation, and social responsibility, and 31 evaluation indicators.

This study systematically developed the framework to evaluate green construction sites while projects are being constructed. The framework indicators are critically identified and verified, which can benefit contractors and builders to assess and benchmark their performance in construction activities and project management. The developed evaluation indicators and framework are not only for rating the green performance of construction projects, but also provide pathways, technologies, and techniques to improve their green construction performance. More importantly, the results contribute to the theoretical research and practical application of green construction. The outcomes from this work can and should be applied to the education of our student cohorts to ensure an enhancement of their sustainability knowledge.

Although the developed framework could be used for all kinds of construction sites in the world, the building construction sites in Australia are focused, as the verification experts are all from the building construction industry in Australia. However, although this framework had been verified by expert evaluation, it has not been tested on construction sites. Further studies could further evaluate and test the evaluation systems on construction sites. It is a long-term study process to improve the performance of green construction in Australia. Therefore, how to promote and apply the framework to assess construction projects in the Australian construction sector shall be further studied, with an emphasis on the education system.

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