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Sustainable technologies for building construction

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Abstract

Global warming and climate change are critical challenges, with the building sector as one of the largest contributors. Conventional construction practices, relying on energy-intensive materials and technologies, not only harm the environment but also pose risks to human health. Addressing these issues requires a shift toward sustainable, or "green," building design. Sustainable construction replaces harmful materials and methods with eco-friendly alternatives that reduce resource consumption and environmental impact. This study explores sustainable technologies, materials, and standards that support buildings in minimizing energy and resource use. Sustainable buildings promise a healthier environment by optimizing water, energy, and material efficiency while reducing emissions. The research also examines the multifaceted benefits of sustainable practices in construction and outlines future directions to advance this approach. Sustainable building practices hold the potential to create environmentally friendly and resource-efficient structures, contributing to a resilient and healthier society.

Keywords: Development; sustainable cycle; sustainable technologies;technological strategies

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1. INTRODUCTION

The building and construction sector is one of the most energy- and waste-intensive industries globally. According to the United Nations Environment Programme's report on the Global Alliance for Buildings and Construction, carbon emissions from building operations reached approximately 10 billion tons in 2019, accounting for 28% of global emissions from energy-related industries. In China, the sector was responsible for 39% of national carbon emissions, with building construction alone contributing 18%. The primary sources of these emissions are electricity consumption and the use of traditional fossil fuels. Therefore, proactive measures in decarbonization, energy conservation, and environmental protection are essential throughout the building lifecycle to achieve sustainability (UNEP, 2020; Masoumi-Hajiagha et al., 2024).

While disruptive technologies associated with Industry 4.0 and digitalization show significant promise for promoting sustainable building practices, researchers have identified challenges in integrating these often virtual and intelligent technologies within the physical building environment. As a result, construction lags behind other industries in adopting these cutting-edge technologies (Opoku et al., 2021; Gawer, 2014). This study explores the role of technological innovation in advancing sustainable construction and examines how such technological transformations can be localized. Disruptive technologies, which have the potential to replace traditional building methods, could drive the sector toward sustainability, primarily through digitalization, big data, smart automation, and energy conservation (Lu et al., 2024; Opoku et al., 2021; Gawer, 2014).

This study investigates the progress of technological innovation and its application in sustainable building construction, focusing on the possibility of localizing these advancements. Disruptive technologies refer to innovations capable of replacing conventional building methods and driving sustainability within the sector (Bower & Christensen, 1995). Successful adoption of these technologies requires overcoming barriers such as the bulky nature of construction products, insufficient research and development funding, and organizational challenges. Clear pathways for applying disruptive technologies to the building sector are essential for realizing a more sustainable world. Despite numerous studies exploring the use of disruptive technologies in construction, few have systematically outlined how these technologies can contribute to specific sustainability goals.

Sustainability, in the context of building and construction, involves minimizing waste and environmental impacts, conserving energy and resources, and ensuring high levels of efficiency and safety throughout the building lifecycle, which includes planning, design, construction, operation, maintenance, and demolition (Cellura et al., 2017; Vanegas et al., 1996; Çetin et al., 2021; Primožič & Kutnar, 2024). However, existing research does not sufficiently address how disruptive digital or Industry 4.0 technologies can help achieve these objectives. Although the building industry is often localized, research on place-based technological advancements supporting sustainability in construction is scarce, and the key local contributors to industry transformation remain unclear (Won et al., 2022; Power, 2008; Ding, 2013; Papadopoulos et al., 2002; Huang et al., 2012).

This research aims to fill this gap by synthesizing the pathways through which 14 technologies contribute to sustainability objectives in construction, based on an analysis of existing literature and patent trends. The study focuses on the Yangtze River Delta (YRD) in China, one of the country's fastest-urbanizing regions and the largest construction market. This approach goes beyond basic analyses of emerging technologies and provides a contextualized understanding of how technological innovation can lead to creative building designs that support sustainability goals.

1.1. Literature review

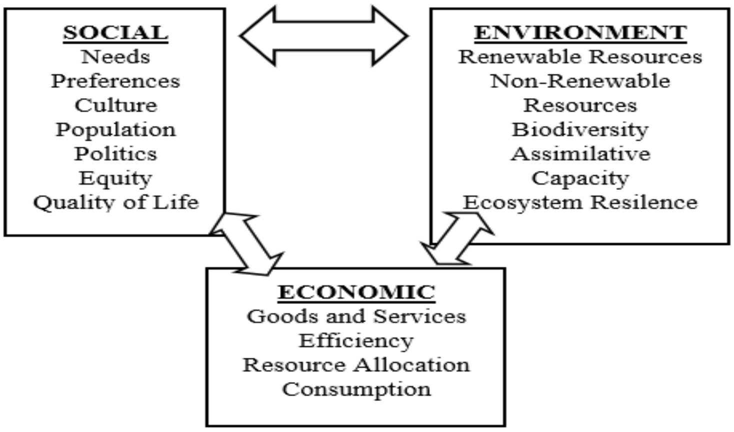
1.1.1. The new paradigm: sustainable development through cycles

Sustainability is a fine balance between constantly shifting social, environmental, and economic realities and constraints, as seen in Figure 1. Sustainable development is the ongoing process of planning and directing human endeavors. It seeks to provide opportunities for present and future generations to meet their needs and aspirations without denying them. Because sustainability is a dynamic field, decision-makers must be flexible enough to modify their strategies in response to shifting environmental conditions, shifting human needs and preferences, and advances in technology.

Sustainability is a dynamic concept rather than a static one. Behaviors that seem viable in the present could be considered harmful in the future should the circumstances significantly alter. A dynamic equilibrium between an increasing human population, the physical environment's changing ability to absorb waste from human activity, the opportunities provided by new knowledge and technology, and the institutions, values, and aspirations that shape human behavior are all necessary to maintain sustainability over time (Pirages, 1994).

Figure 1

The sustainability context



Source: Vanegas et al. (1996).

The crucial social, environmental, and economic elements that are essential to sustainability are examined in the sections that follow. In the sections of this paper that follow, these factors will be applied to the building and construction sector. Fostering an approach that is truly sustainable in the construction industry requires an understanding of and attention to these crucial elements.

1.1.2. Social sustainability

Sustainability is inherently anthropocentric, as it centers on human welfare and the desire to thrive, not merely to survive. It reflects the aspiration to live the best possible life, ensuring that future generations can do the same. However, numerous sociocultural challenges impact environmental sustainability, with intergenerational equity being one of the most critical issues. We must ensure that future generations have the resources and opportunities to live well (Waheeb, 2023). An African proverb aptly captures this idea: "We are not the earth's owners; we are just caretakers of the inheritance left for our grandchildren." This perspective highlights the importance of not sacrificing the quality of life enjoyed by people today. Instead, we must focus on improving the lives of those who lack access to necessities like food and clean water. Environmental justice is another key concern, emphasizing fairness in the distribution of environmental benefits and burdens. Alongside environmental factors, human health, cultural needs, personal preferences, and population growth all significantly influence our quality of life and must be considered alongside economic factors, which are often easier to measure but should not overshadow these broader social and environmental concerns.

1.1.3. Environmental sustainability

Sustainability also requires careful consideration of environmental issues. The physical setting in which we exist is called the natural environment. To be sustainable, we must acknowledge the boundaries of our surroundings. There are restrictions on the number of natural resources that the earth has to offer. A few of these resources, like wildlife and trees, are renewable as long as we preserve enough material for future growth. Additional resources, like minerals, replenish so slowly that any use whatsoever reduces the overall supply. We must reduce the amount of all resources that we use, both renewable and finite.

Minimizing the impact on global ecosystems is another crucial environmental issue (Bibri, 2020). We need to keep the earth in a healthy state because it is like an organism. Natural ecosystems can withstand certain impacts, but they must be minimal enough for the earth to be able to bounce back (Hanafi, 2021). Sometimes specific resources or ecosystem components are present. Which are necessary for its well-being. For instance, even though we seem to be producing enough wood for future generations, our efforts might not be sufficient if it is all kept in managed monoculture forests, which are unable to replicate the complexity of ecosystems (Norton, 1992). Preserving the health of an ecosystem could entail safeguarding an endangered species, the protection of biodiversity overall, or the preservation of a wetland.

1.1.4. Economic sustainability

Economics, in the context of sustainability, extends beyond traditional measures such as GDP, exchange rates, inflation, and profit. As a social science, economics plays a vital role in sustainability by examining how goods and services are produced, distributed, and consumed. The trade of goods and services significantly impacts the environment, serving as both a major source of raw materials and a final destination for discarded products. Much of the unsustainable development in the past has been driven by economic gain, often at the expense of environmental health. The shift toward sustainability will not occur until it is demonstrated that sustainable practices are not only viable but also economically advantageous. Adaptation is a key aspect of sustainability, which involves assigning value to products with consideration for the financial losses incurred from the depletion or degradation of natural resources. To achieve sustainability, we must broaden our focus to include long-term consequences, rather than only immediate ones. Once this broader perspective is adopted, sustainable development will become a more economically attractive alternative to the current trajectory of growth.

1.1.5. Role of technology

Environment The environment plays a crucial role in sustainable development. Technology enables us to extract natural resources, modify them for human use, and adapt our built environments to meet our needs. This technological progress has led to significant improvements in the quality of life for many. However, these short-term gains have often come at a significant cost to the environment. Achieving sustainability will require a more thoughtful and deliberate approach to how we use technology. Focus on creating and implementing technologies that prioritize sustainability is referred to as "sustainable technologies." To avoid ambiguity and ensure clarity, it is important to define "technology" within this context. In this essay, "technology" is understood as "the utilization of knowledge to achieve specific objectives or solve particular problems" (Moore, 1972). Therefore, technology encompasses more than just the physical tools we use daily; it also includes symbols, processes, and other intangible elements such as economic transactions and language. These elements act as interfaces between humans and the environment, enabling us to take action toward solving problems and advancing sustainability.

1.2. Purpose of study

The objective of sustainable technology in the building construction industry is to minimize environmental impact, conserve resources, and enhance long-term viability. The scope includes adopting eco-friendly materials, energy-efficient designs, and innovative construction methods to create structures that prioritize environmental and social responsibility while meeting economic needs.

2. METHOD AND MATERIALS

2.1. Data collection instrument

Data was collected with the help of a questionnaire. Tan (2011) claims that a questionnaire survey is a systematic way to collect data using a sample. In green building research, the questionnaire survey method has been widely utilized to gather expert opinions (Xue et al., 2016; Zhu et al., 2017). An empirical questionnaire survey was used in this study. Conducted to ascertain the relative significance of the suggested tactics in encouraging the adoption of GBTs.in the building sector. It is beneficial to conduct a questionnaire survey on" Objectivity and quantifiability" (Ackroyd & Hughes 1992). The extensive literature review served as the foundation for creating the survey questions. There were three sections to the main questionnaire. Part I contained their research objectives and contact information. The purpose of Part II was to gather background details about the experts, such as their position, years of experience, and occupation. Next, in Section III, a list of 21 factors encouraging the adoption of GBTs, a list of 26 obstacles to their adoption, and a list of there were twelve promotion strategies for GBT adoption that were showcased. The specialists were first requested to Determine how serious the obstacles to the adoption of GBTs are by using a five-point Likert scale that ranges from ranging from 1 (not urgent) to 5 (extremely urgent). Furthermore, the specialists were requested to provide their expert views on the primary motivators for implementing GBTs on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). Lastly, the significance of each tactic was put to the experts' evaluation. When encouraging the use of GBTs, a five-point Likert scale with 1 representing "not important" to (crucially important). The middle number for each of the five-point Likert scales was three, which represents neutrality. The only query that the public is interested in is the one about the promotion tactics for the adoption of GBTs. The five-point Likert scale was used in this study because it produces results that are clear and simple to understand. Furthermore, the field of green building has seen a rise in the use of five-point Likert scales (Zhang et al., 2011; Hwang et al., 2017). An aviator study was carried out to evaluate the questionnaire's appropriateness and comprehensibility before the survey. A group of three professors, a senior lecturer, and a postgraduate student participated in the pilot study researchers with prior expertise in this field of study. The majority of them, particularly the instructors, had both business and academic/research backgrounds in green building. The completed questionnaire was submitted. According to the pilot study's feedback.

2.2. Participants

The questionnaire was distributed via email to a carefully selected group of global green building experts, including academics and practitioners, primarily identified through research publications and member directories of global Green Building Councils. In this study, an expert is defined as someone with specific skills or expertise, demonstrated through leadership roles in professional associations, speaking engagements at national conferences, or authorship of articles in reputable publications (Cabaniss, 2002). To preserve anonymity, the suitability of the selected experts was based on their knowledge of Green Building Technologies (GBT) and practices in the construction industry, as reflected in their relevant research or certifications from reputable Green Building Councils, such as the World Green Building Council, the UK Green Building Council, the US Green Building Council (USGBC), Canada Green Building Council, and the Green Building Council of Australia. Purposive sampling was employed to gather data, a non-probability technique that selects informed specialists aligned with the study's objectives (Tongco, 2007). While bias is inherent in all research, efforts were made to minimize it through these strategies. Purposive sampling was particularly beneficial as it allows for continuous adjustment of the sample to meet the study's goals, reducing bias compared to convenience sampling (Smith & Noble, 2014). To further mitigate bias, the survey underwent pretesting via a pilot study to ensure a well-designed research tool. Additionally, to reduce non-response bias, frequent email reminders were sent during the data collection phase (Beeken et al., 2012).

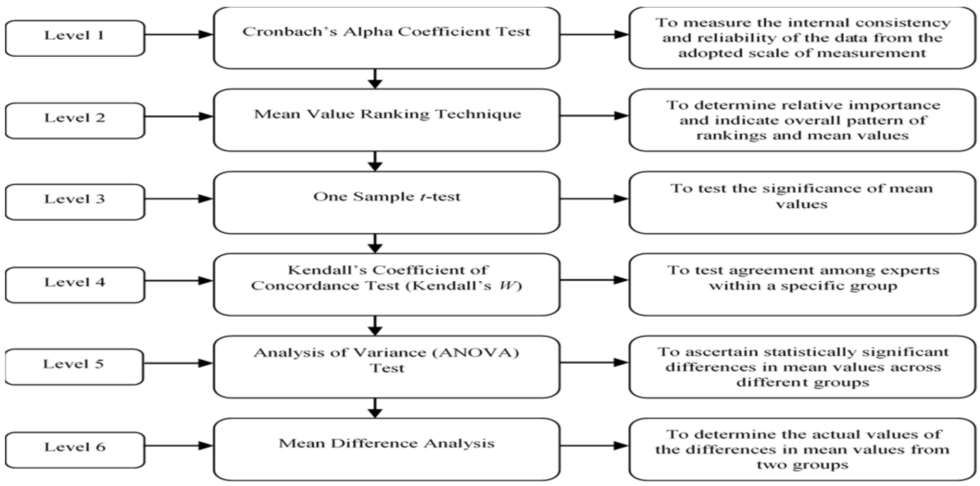
Each expert received the questionnaire via email, along with a Microsoft Word document and a SurveyMonkey-generated web link for online responses. Due to resource constraints, only an English version of the survey was used, assuming the majority of the selected experts were proficient in English. To encourage participation, experts were informed that the research findings would be shared with them, and they were asked to forward the questionnaire to other knowledgeable colleagues in the industry. As a result, the exact distribution of the survey is unknown, but over 500 questionnaires were sent out. The survey ran for three months, starting in early March, and resulted in 104 valid responses from green building specialists across 20 countries, including the US, Canada, Australia, the UK, China, Hong Kong, Malaysia, Singapore, Mexico, Brazil, India, and Egypt. Given the challenges of obtaining responses from international sources (Cheng & Li, 2002), 104 responses from reputable experts are considered reasonable and representative. Many scholars suggest that a sample size of at least 30 is sufficient for meaningful analysis (Ott & Longnecker, 2010; Zhao et al., 2016). Due to space constraints, detailed information on the number of responses from each country and the background of the specialists is documented elsewhere (Chan et al., 2017). The study's findings are highly reliable and credible, as indicated by the experts' professional backgrounds. Most respondents held senior positions, including senior managers (26%), directors/CEOs (21%), and professors (19%). Additionally, the majority had practical experience in implementing green building projects or participating in green building initiatives, with 59% actively involved in these projects. Furthermore, 71% of the experts had more than five years of experience in the field of green building.

2.3. Analysis

The statistical analysis of the gathered data was conducted with the SPSS 20.0 software. The present investigation employed diverse statistical analysis techniques to conduct data analyses within a six-level data analyses framework (Figure 2), which was adapted from Choi's (2012) five-level data analyses framework. as well as Wong et al.'s six-level framework for data analysis (Darko et al., 2017). Consequently, the data analysis of the current study's framework includes six distinct statistical analysis methods: (1) Cronbach's sample t-test, the alpha coefficient test, the mean value/score ranking method, and Kendall's (5) analysis of variance (ANOVA) test; (6) mean difference analysis (Figure 1); and (7) coefficient of concordance test (Kendall's W). First, the data's reliability for additional analysis was evaluated using the Cronbach's alpha coefficient test. The Cronbach's alpha coefficient evaluates dependability by looking at the internal consistency within the chosen measurement scale (Santos, 1999). Second, the ranking of the mean values approach was employed to ascertain the proposed promotion's relative importance and rankings. techniques for implementing GBTs. In studies on construction management, the mean value ranking method has been extensively employed and regarded as a successful technique to quickly identify important components among multiple personal elements (Chan et al., 2004; Chan et al., 2010). Third, the significance of the mean values of the importance of the promotion strategies was tested using the one-sample t-test (Darko et al., 2017; Zhao et al., 2016). Furthermore, Kendall's W was computed to assess the degree of consensus among various green building specialists regarding their rankings of promotional tactics. 2017; of 18 inside a particular group (Shi et al., 2013). This study used Kendall's W because it makes no assumptions about the particular distribution of data (Lam et al., 2015). Additionally, the ANOVA test was used to determine statistically. There are notable variations in the significance mean values of the promotion strategies among various expert groups (Chan et al., 2017; Rahman, 2014). Since the ANOVA test is a useful technique for comparing the mean values of more than two groups, it was selected over alternative tests like the Mann-Whitney U Test (Pallant, 2020). Finally, the actual values of the differences in the mean were ascertained through the mean difference analysis. Significance means the values of the two groups' promotion strategies (Hwang et al., 2017).

Figure 2

Six-level data analysis framework



Source: Chan et al. (2017).

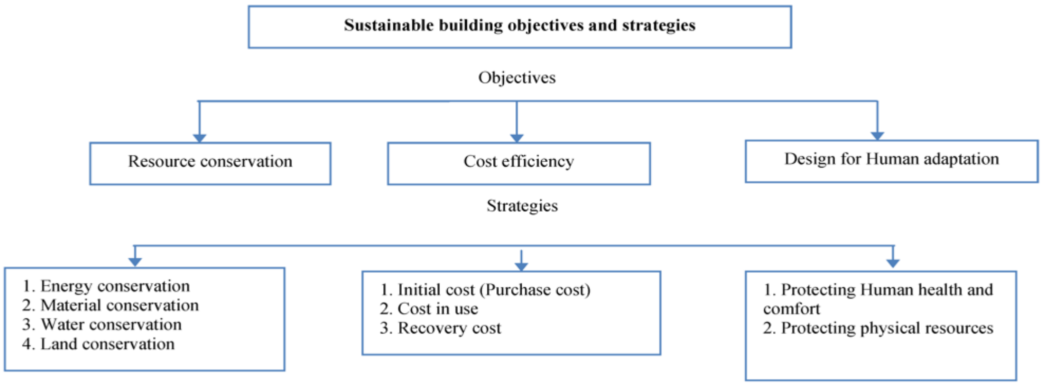
3. RESULTS

3.1. Sustainable implementation; a framework of strategies and method

According to Asif et al., (2007), a multidisciplinary approach encompassing various aspects like energy conservation, enhanced material utilization, reduction of material waste, pollution and emissions management, and so on, is recommended to attain a sustainable future in the building industry. Without sacrificing the building activities' valuable output, there are numerous ways to regulate and enhance the current nature of building activity to make it less harmful to the environment. Therefore, the whole life cycle of buildings should be the context in which environmentally friendly construction practices are implemented to gain a competitive advantage. Three overarching goals have been identified through a review of the literature. These goals should inform the framework for implementing sustainable building design and construction (Figure 3), while also bearing in mind the previously identified (social, environmental, and economic). These goals are as follows: Resource conservation; Cost efficiency and; Design for Human adaptation.

Figure 3

Framework for implementing sustainability in building construction



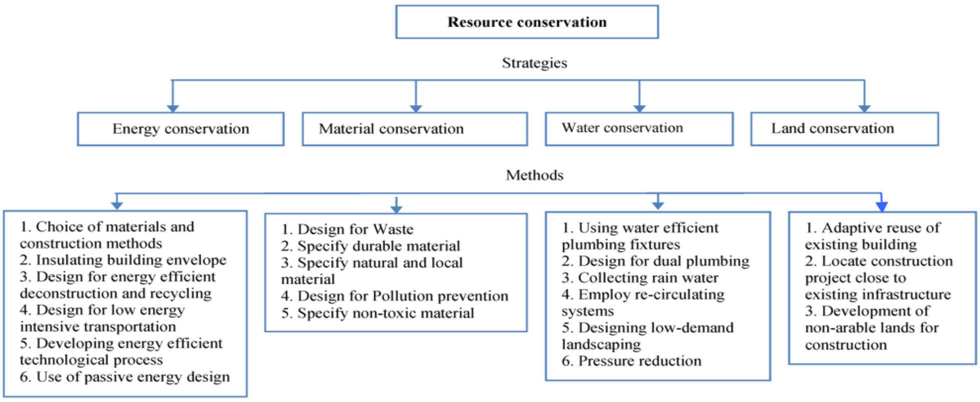
Source: Akadiri et al., (2012).

3.1.1. Objective 1: Resource conservation

To "conserve resources" is to do more with less. To maximize benefits to present generations while preserving the ability to meet the needs of future generations, is the management of human use of natural resources (Schimschar et al., 2011). The idea has grown to be a contentious topic in discussions of sustainable development. According to Halliday (2008), some resources are getting incredibly scarce, so using what is left should be done with caution. The author advocated using less rare or renewable materials in place of rare materials. In policy circles, bold claims regarding the necessity of drastic improvements in the use of materials and energy resources have gained recognition. It is argued that increasing productivity is required to reduce the effects on natural systems' ability to absorb waste and energy (Halliday, 2008). Since the building sector consumes a significant number of natural resources, many efforts to create ecologically sustainable buildings center on improving resource efficiency, as stated by Graham (2009). He said there are several approaches used to search for these efficiencies. The concepts of solar passive design, which tries to lower the consumption of non-renewable resources, the consumption of energy production, life cycle design, and construction design, were among the examples he gave. Improved resource consumption efficiency is achieved through techniques that reduce material waste during the building process and provide opportunities for recycling and reusing building materials. Growing concerns about the depletion of non-renewable natural resources have led to increased calls for resource efficiency. The preservation of these resources is critical for a sustainable future, as energy, water, materials, and land are among the most commonly used non-renewable resources in construction projects. Figure 4 defines the specific design strategies and methods that result from resource conservation.

Figure 4

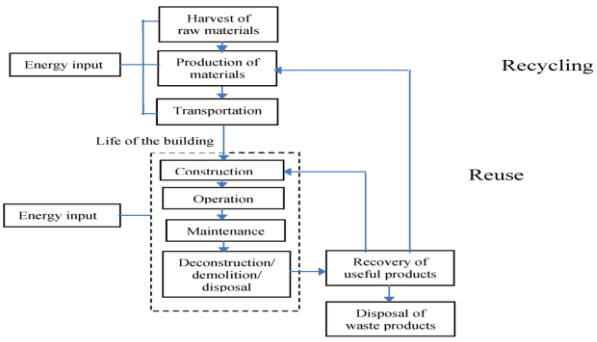
Strategies and Methods to achieve resource conservation



Source: Akadiri et al., (2012).

Figure 5

Stages of energy input during the life of a building



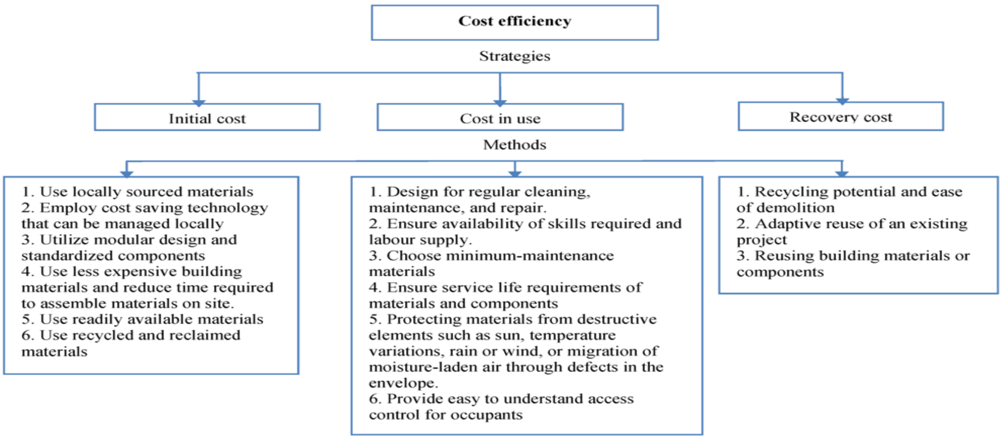
Source: Akadiri et al., (2012).

3.1.2. Objective 3: Water conservations

The world's top environmental concern today is the depletion of water resources due to the rapid growth of the global economy. A water crisis is emerging as a result of the scarcity of water for all human needs, according to the United Nations World Water Development Report (WWDR) (Nations, 2003). The building industry is one where a sector's effects on the environment are most evident (McCormack et al., 2007). The process of building requires a lot of water from the surrounding environment. Water tables have significantly dropped as a result of increased urban water use, necessitating large-scale projects that divert resources from agriculture (Roodman et al., 1995). Water consumption in construction represents a significant portion of a country's total water use, but water is also consumed throughout a building's entire life cycle. In addition to its use during the on-site construction process, water is involved in the extraction, production, manufacturing, and delivery of materials to the site. McCormack et al. (2007) referred to this water as "embodied" water. Despite its importance, water conservation strategies and technologies are often the most overlooked aspects of a comprehensive building design strategy (Ilha et al., 2009). However, due to increasing awareness of the potential water savings from adopting water-saving initiatives, the planning of diverse water uses within buildings is becoming a more critical focus. The literature reveals numerous strategies (Ilha et al., 2009; McCormack et al., 2007; Sev, 2009) that can be employed to reduce water usage throughout a building's life cycle.

Figure 6

Strategies and Methods to achieve cost efficiency



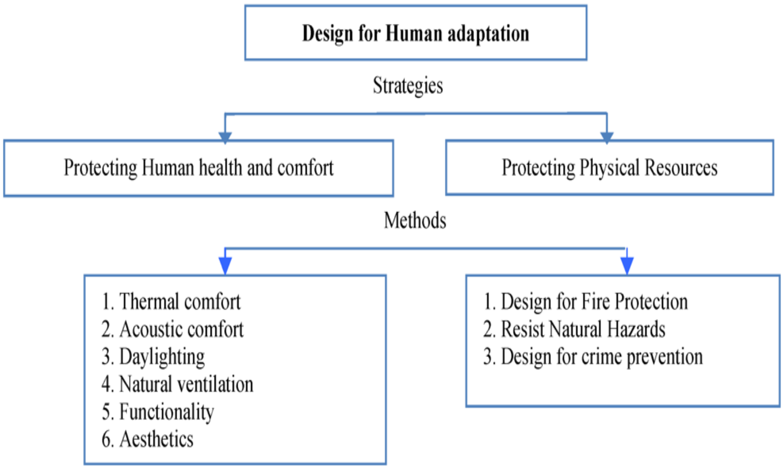
Source: Akadiri et al., (2012).

3.1.3. Objective 3: Design for human adaptation

Ensuring that human activities take place in a healthy and comfortable environment is one of the primary goals of sustainable buildings. A building must have enough floor space, room volume, lighting, shelter, and other amenities for people to work, live, learn, cure, process, and other purposes for which it was designed. In addition, the building needs to provide its occupants with a comfortable and healthy indoor environment. For the building to satisfy these fundamental standards, it must, among other things, be structurally sound and fire-safe and must not endanger the environment or its occupants. To be considered sustainable, a building must not add needlessly to the load on it or pose an environmental risk, such as through excessive energy use. The next two design techniques ought to be taken into account to encourage and improve human adaptability (Figure 7).

Figure 7

Strategies and Methods to achieve human adaptation



Source: Akadiri et al., (2012).

3.2. Sustainability and the building construction

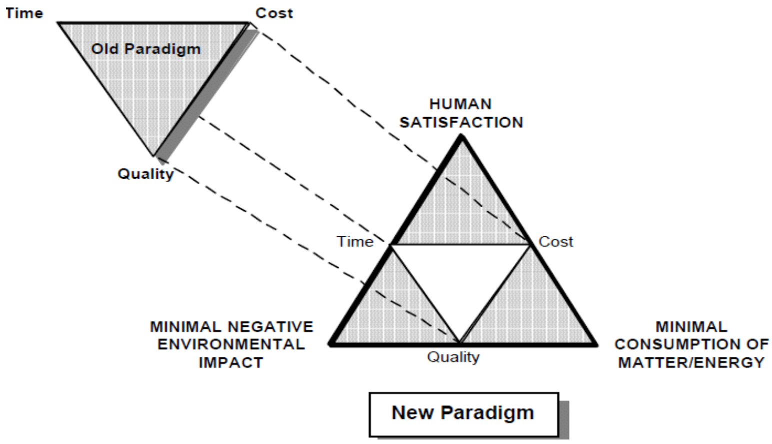
Sustainable design and construction add to the traditional design and construction criteria of cost, performance, and quality objectives by minimizing resource depletion and environmental degradation and fostering the creation of a healthy built environment and surroundings (Kibert 1994). Figure 8 depicts the main paradigm change to sustainability in the field of building architecture and construction. This new model Sustainability paradigm highlights issues that should be taken into account when designing anything at all.

Phases of the facility's life cycle. Sustainable builders and designers will tackle every project considering not just the initial capital outlay but also the facility's full life cycle. Rather than considering the constructed environment to be an entity apart from the surrounding environment, it ought to be considered as a component of the naturally occurring flow and exchange of matter and energy inside the biosphere. Apart from the inanimate elements that comprise the constructed, environmentally friendly designers and builders must also take into account the living elements of the built environment, that is people, animals, and plants that work together as a complete system of other biosphere ecosystems.

The life cycle of a facility encompasses more than just building the facility itself, life cycle considerations are especially crucial when it comes to the design and construction of built facilities. Operation, upkeep, and disposal or decommissioning of the building also use materials and energy, with the majority of their usage being limited by design as well as choices made during the facility's early construction. Not only are modifications that are less difficult to make when designing the facility but also the modifications' costs are reduced because the facility is merely "on paper" rather than a tangible relic. Which, once construction is started and completed, actually exists. Furthermore, selections of additional expensive design elements included in the construction of the facility and design may be offset by price, and savings in terms of resources and energy over the facility's life cycle. Consequently, the principal onus of developing sustainable built environments rests with the designers and builders of these kinds of facilities.

Figure 8

Paradigm shift from traditional to sustainable design and construction



Source: Vanegas et al., (1996).

4. CONCLUSIONS

Most sustainable technologies are retrofitted into already-existing buildings to maximize energy savings. Nonetheless, the findings suggest that customers and possible financiers are drawn to the apparent advantages of rebuilding instead of renovating using STs. However, it counters some research that elaborated on the benefits of maintenance as opposed to complete building demolition. Some contend that the demolition and construction approach creates several environmental problems as well. Savings are frequently made to project payback duration. This facilitates decision-making for investors and clients regarding the purchase of sustainable technology. Unfortunately, the cost of some of the technologies affects payback times. Due to the lengthy time needed to recover invested capital as well as interest on capital, this deters clients from making investments.

Due to costs and unsatisfactory economic returns, energy efficiency renovation measures are frequently avoided as a result of poor payback periods. It is important to try to increase payback time because it impacts energy savings in older buildings. This is significant because it becomes challenging to recoup the financial investment due to unacceptably long payback periods. There is a belief that increases in energy efficiency do not result in estimated energy savings. This influences how people adopt and use STs. This is, in fact, a significant obstacle to the adoption of STs and the associated sustainability of the environment. There is a belief that these technologies can't achieve the required levels of energy savings. The Australian Energy Efficiency Council was forced to introduce different levels of sustainable renovations and upgrades because, in certain cases, a lack of energy efficiency policies slows down the adoption of energy-saving technologies. The first kind of energy-efficient remodeling is simple and requires little effort to adopt and install advanced energy-saving technologies. This is an effort to increase the market for STs.

Attempts to adopt STs are further hampered by the nature of current building designs, which is a major source of concern. For instance, an existing building's flooring system must be completely replaced to install the underfloor air distribution system. Clients and investors frequently steer clear of these additional tasks because they raise the cost of renovation. The same is true of a building's current façade, which discourages the introduction of highly energy-efficient technologies due to its design and construction. Sometimes completely demolishing the building envelope is necessary to make room for newly developed technologies. Nevertheless, the cost of these measures prevents the introduction of new STs.

As a result, the results can help academics, government organizations, and specialists in energy efficiency critically examine potential approaches to enhancing energy-saving measures for already-existing buildings. Nine issues affecting the adoption and application of STs to increase energy savings in Australia's existing buildings have been detailed in this study.

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Ethical Approval: The study adheres to the ethical guidelines for conducting research.

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REFERENCES

Ackroyd, S., & Hughes, J. A. (1992). Data collection in context.

Akadiri, P. O., Chinyio, E. A., & Olomolaiye, P. O. (2012). Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings*, *2*(2), 126-152. https://www.mdpi.com/2075-5309/2/2/126

Asif, M., Muneer, T., & Kelley, R. (2007). Life cycle assessment: A case study of a dwelling home in Scotland. *Building and Environment*, *42*(3), 1391-1394. https://www.sciencedirect.com/science/article/pii/S0360132305004956

Beeken, R. J., Croker, H., Morris, S., Leurent, B., Omar, R., Nazareth, I., & Wardle, J. (2012). Study protocol for the 10 Top Tips (10TT) Trial: A randomised controlled trial of habit-based advice for weight control in general practice. *BMC Public Health*, *12*, 1-10. https://link.springer.com/article/10.1186/1471-2458-12-667

Bibri, S. E. (2020). The eco-city and its core environmental dimension of sustainability: green energy technologies and their integration with data-driven smart solutions. *Energy Informatics*, *3*(1), 4. https://link.springer.com/article/10.1186/s42162-020-00107-7

Bower, J. L., & Christensen, C. M. (1995). Disruptive technologies: Catching the wave. https://www.academia.edu/download/59516552/disruptive_technologies20190604-89196-pd4gyy.pdf

Cabaniss, K. (2002). Computer-related technology use by counselors in the new millennium: A Delphi study. *Journal of Technology in Counseling*, *2*(2). https://www.learntechlib.org/p/95642/

Cellura, M., Guarino, F., Longo, S., & Mistretta, M. (2017). Modeling the energy and environmental life cycle of buildings: A co-simulation approach. *Renewable and Sustainable Energy Reviews*, *80*, 733-742. https://www.sciencedirect.com/science/article/pii/S136403211730919X

Çetin, S., De Wolf, C., & Bocken, N. (2021). Circular digital built environment: An emerging framework. *Sustainability*, *13*(11), 6348. https://www.mdpi.com/2071-1050/13/11/6348

Chan, A. P. C., Darko, A., & Ameyaw, E. E. (2017). Strategies for promoting green building technologies adoption in the construction industry—An international study. *Sustainability*, *9*(6), 969. https://www.mdpi.com/2071-1050/9/6/969

Chan, A. P., Chan, D. W., Chiang, Y. H., Tang, B. S., Chan, E. H., & Ho, K. S. (2004). Exploring critical success factors for partnering in construction projects. *Journal of construction engineering and management*, *130*(2), 188-198. https://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-9364(2004)130:2(188)

Chan, A. P., Darko, A., Ameyaw, E. E., & Owusu-Manu, D. G. (2017). Barriers affecting the adoption of green building technologies. *Journal of Management in Engineering*, *33*(3), 04016057. https://ascelibrary.org/doi/abs/10.1061/(ASCE)ME.1943-5479.0000507

Chan, A. P., Lam, P. T., Chan, D. W., Cheung, E., & Ke, Y. (2010). Critical success factors for PPPs in infrastructure developments: Chinese perspective. *Journal of construction engineering and management*, *136*(5), 484-494. https://ascelibrary.org/doi/abs/10.1061/(ASCE)CO.1943-7862.0000152

Cheng, E. W., & Li, H. (2002). Construction partnering process and associated critical success factors: quantitative investigation. *Journal of management in engineering*, *18*(4), 194-202. https://ascelibrary.org/doi/abs/10.1061/(ASCE)0742-597X(2002)18:4(194)

Choi, N. Y. (2012). Investigating the current application and exploring the future development of the pay-for-safety scheme (PFSS) in the Hong Kong construction industry. https://theses.lib.polyu.edu.hk/handle/200/6950

Darko, A., Chan, A. P. C., Ameyaw, E. E., He, B. J., & Olanipekun, A. O. (2017). Examining issues influencing green building technologies adoption: The United States green building experts' perspectives. *Energy and Buildings*, *144*, 320-332. https://www.sciencedirect.com/science/article/pii/S0378778816314578

Darko, A., Chan, A. P., Owusu-Manu, D. G., & Ameyaw, E. E. (2017). Drivers for implementing green building technologies: An international survey of experts. *Journal of Cleaner Production*, *145*, 386-394. https://www.sciencedirect.com/science/article/pii/S0959652617300501

Ding, G. (2013). Demolish or refurbish-environmental benefits of housing conservation. *Australasian Journal of Construction Economics and Building, The*, *13*(2), 18-34. https://search.informit.org/doi/abs/10.3316/INFORMIT.399866119215848

Gawer, A. (2014). Bridging differing perspectives on technological platforms: Toward an integrative framework. *Research Policy*, *43*(7), 1239-1249. https://www.sciencedirect.com/science/article/pii/S0048733314000456

Graham, P. (2009). *Building ecology: First-principles for a sustainable built environment*. John Wiley & Sons. https://books.google.com/books?hl=en&lr=&id=zyCHMQQifTwC&oi=fnd&pg=PR7&dq=Graham,+P.+Building+Ecology%E2%80%94First+Principles+for+a+Sustainable+Built+Environment%3B+Blackwell,+Publishing:+Oxford,+UK,+2003.+&ots=OGj8yeKBNF&sig=ICdaRm2sF6xwndKy5EF3O11KhXU

Halliday, S. (2008). *Sustainable construction*. Routledge. https://www.taylorfrancis.com/books/mono/10.4324/9780080557168/sustainable-construction-sandy-halliday

Hanafi, W. H. H. (2021). Compressed stabilized earth block: an environmentally sustainable alternative for village housing. *Journal of Engineering and Applied Science*, *68*(1), 20. https://link.springer.com/article/10.1186/s44147-021-00017-9

Hodges, N. (2011). Qualitative research: A discussion of frequently articulated qualms (FAQs). *Family and Consumer Sciences Research Journal*, *40*(1), 90-92. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1552-3934.2011.02091.x

Huang, Y., Niu, J. L., & Chung, T. M. (2012). Energy and carbon emission payback analysis for energy-efficient retrofitting in buildings—Overhang shading option. *Energy and Buildings*, *44*, 94-103. https://www.sciencedirect.com/science/article/pii/S0378778811004725

Hwang, B. G., Zhu, L., & Ming, J. T. T. (2017). Factors affecting productivity in green building construction projects: The case of Singapore. *Journal of Management in Engineering*, *33*(3), 04016052. https://ascelibrary.org/doi/abs/10.1061/(ASCE)ME.1943-5479.0000499

Ilha, M. S. D. O., Oliveira, L. H. D., & Gonçalves, O. M. (2009). Environmental assessment of residential buildings with an emphasis on water conservation. *Building Services Engineering Research and Technology*, *30*(1), 15-26. https://journals.sagepub.com/doi/abs/10.1177/0143624408098274

Imperatives, S. (1987). Report of the World Commission on Environment and Development: Our common future. *Accessed Feb*, *10*(42,427). http://www.ask-force.org/web/Sustainability/Brundtland-Our-Common-Future-1987-2008.pdf

Kibert, C. J. (1994). Establishing principles and a model for sustainable construction. In *Proceedings of the first international conference on sustainable construction* (pp. 6-9). Tampa, FL: CIB Publications TG 16, Roterdão.

Lam, P. T., Chan, E. H., Ann, T. W., Cam, W. C., & Jack, S. Y. (2015). Applicability of clean development mechanism to the Hong Kong building sector. *Journal of Cleaner Production*, *109*, 271-283. https://www.sciencedirect.com/science/article/pii/S0959652615007623

Li, Y. Y., Chen, P. H., Chew, D. A. S., Teo, C. C., & Ding, R. G. (2011). Critical project management factors of AEC firms for delivering green building projects in Singapore. *Journal of construction engineering and management*, *137*(12), 1153-1163. https://ascelibrary.org/doi/abs/10.1061/(ASCE)CO.1943-7862.0000370

Lu, W., Lou, J., Ababio, B. K., Zhong, R. Y., Bao, Z., Li, X., & Xue, F. (2024). Digital technologies for construction sustainability: Status quo, challenges, and prospects. *npj Materials Sustainability*, *2*(1), 10. https://www.nature.com/articles/s44296-024-00010-2

Masoumi-Hajiagha, A., Heravi, G., & Khosravi, H. (2024). Development of a Framework for Optimal Selection of Sustainable Building Envelopes using BIM. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 1-17. https://link.springer.com/article/10.1007/s40996-024-01644-x

McCormack, M., Treloar, G. J., Palmowski, L., & Crawford, R. (2007). Modeling direct and indirect water requirements of construction. *Building research and information*, *35*(2), 156-162. https://www.tandfonline.com/doi/abs/10.1080/09613210601125383

Moore, M. G. (1972). Learner autonomy: The second dimension of independent learning. *Convergence*, *5*(2), 76. https://search.proquest.com/openview/026768752863637ca2c2f4efd6eb0140/1?pq-origsite=gscholar&cbl=2030445

Nations, U. (2003). Water for people, water for life: The United Nations World Development Report. *UNESCO Publishing/Berghahan Books*.

Norton, B. (1992). Sustainability, human welfare, and ecosystem health. *Environmental values*, *1*(2), 97-111. https://journals.sagepub.com/doi/abs/10.3197/096327192776680133

Opoku, D. G. J., Perera, S., Osei-Kyei, R., & Rashidi, M. (2021). Digital twin application in the construction industry: A literature review. *Journal of Building Engineering*, *40*, 102726. https://www.sciencedirect.com/science/article/pii/S2352710221005842

Ott, R. L., & Longnecker, M. (2010). *An introduction to statistical methods and data analysis*. Cengage Learning Inc.. http://repository.bitscollege.edu.et:8080/bitstream/handle/123456789/789/LYMANO~1.PDF?sequence=1

Pallant, J. (2020). *SPSS survival manual: A step-by-step guide to data analysis using IBM SPSS*. Routledge. https://www.taylorfrancis.com/books/mono/10.4324/9781003117452/spss-survival-manual-julie-pallant

Papadopoulos, A. M., Theodosiou, T. G., & Karatzas, K. D. (2002). Feasibility of energy-saving renovation measures in urban buildings: The impact of energy prices and the acceptable payback time criterion. *Energy and buildings*, *34*(5), 455-466. https://www.sciencedirect.com/science/article/pii/S0378778801001293

Pirages, D. (1994). Sustainability as an evolving process. *Futures*, *26*(2), 197-205. https://www.sciencedirect.com/science/article/pii/0016328794901090

Pow, C. P., & Neo, H. (2013). Seeing red over green: Contesting urban sustainabilities in China. *Urban Studies*, *50*(11), 2256-2274. https://journals.sagepub.com/doi/abs/10.1177/0042098013478239

Power, A. (2008). Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social, and economic viability? *Energy policy*, *36*(12), 4487-4501. https://www.sciencedirect.com/science/article/pii/S0301421508004709

Primožič, L., & Kutnar, A. (2024). Key decision factors of professional stakeholders (architects, engineers, constructors) when deciding for sustainable construction. *Frontiers in Built Environment*, *10*, 1420163. https://www.frontiersin.org/articles/10.3389/fbuil.2024.1420163/full

Rahman, M. M. (2014). Barriers of implementing modern methods of construction. *Journal of management in engineering*, *30*(1), 69-77. https://ascelibrary.org/doi/abs/10.1061/(ASCE)ME.1943-5479.0000173

Roodman, D. M., Lenssen, N. K., & Peterson, J. A. (1995). *A building revolution: how ecology and health concerns are transforming construction* (Vol. 124). Washington, DC: Worldwatch Institute. http://www.skidmore.edu/academics/IPC/cec/buildings_energy/greenbuild-article.doc

Santos, J. R. A. (1999). Cronbach's alpha: A tool for assessing the reliability of scales. *Journal of Extension*, *37*(2), 1. https://cir.nii.ac.jp/crid/1370853567425763328

Schimschar, S., Blok, K., Boermans, T., & Hermelink, A. (2011). Germany's path towards nearly zero-energy buildings—Enabling the greenhouse gas mitigation potential in the building stock. *Energy Policy*, *39*(6), 3346-3360. https://www.sciencedirect.com/science/article/pii/S0301421511002096

Sev, A. (2009). How can the construction industry contribute to sustainable development? A conceptual framework. *Sustainable Development*, *17*(3), 161-173. https://onlinelibrary.wiley.com/doi/abs/10.1002/sd.373

Shi, Q., Zuo, J., Huang, R., Huang, J., & Pullen, S. (2013). Identifying the critical factors for green construction–an empirical study in China. *Habitat International*, *40*, 1-8. https://www.sciencedirect.com/science/article/pii/S0197397513000106

Smith, J., & Noble, H. (2014). Bias in research. *Evidence-based nursing*, *17*(4), 100-101. https://ebn.bmj.com/content/17/4/100.short

Tan, W. C. K. (2011). *Practical Research Methods*. Pearson Custom: Singapore.

Tongco, M. D. C. (2007). Purposive sampling as a tool for informant selection. https://scholarspace.manoa.hawaii.edu/handle/10125/227

UNEP. (2020). Report on Global Building and Construction Industrial Development (2020): Toward a Zero-Carbon, High Efficiency and Resilient Building and Construction Industry; Global Alliance for Buildings and Construction: Nairobi, Kenya.

Vanegas, J. A., DuBose, J. R., & Pearce, A. R. (1996). Sustainable technologies for the building construction industry. In *Proceedings, Symposium on Design for the Global Environment, Atlanta, GA*. https://www.academia.edu/download/67046405/Sustainable_technologies_for_the_buildin20210504-12208-1mjwyg8.pdf

Vanegas, J. A., DuBose, J. R., & Pearce, A. R. (1996). Sustainable technologies for the building construction industry. In *Proceedings, Symposium on Design for the Global Environment, Atlanta, GA*. https://www.academia.edu/download/67046405/Sustainable_technologies_for_the_buildin20210504-12208-1mjwyg8.pdf

Waheeb, S. A. (2023). Environmental and cultural sustainability of the architectural elements of two historical mosques in historic Jeddah. *Journal of Umm Al-Qura University for Engineering and Architecture*, *14*(1), 26-35. https://link.springer.com/article/10.1007/s43995-022-00011-z

Won, D., Hwang, B. G., & Binte Mohd Samion, N. K. (2022). Cloud computing adoption in the construction industry of Singapore: Drivers, challenges, and strategies. *Journal of management in engineering*, *38*(2), 05021017. https://ascelibrary.org/doi/abs/10.1061/(ASCE)ME.1943-5479.0001001

Xue, F., Gou, Z., & Lau, S. S. Y. (2016). Human factors in green office building design: The impact of workplace green features on health perceptions in high-rise high-density Asian cities. *Sustainability*, *8*(11), 1095. https://www.mdpi.com/2071-1050/8/11/1095

Zhang, X., Shen, L., & Wu, Y. (2011). Green strategy for gaining competitive advantage in housing development: a China study. *Journal of Cleaner Production*, *19*(2-3), 157-167. https://www.sciencedirect.com/science/article/pii/S0959652610003203

Zhao, X., Hwang, B. G., & Lee, H. N. (2016). Identifying critical leadership styles of project managers for green building projects. *International Journal of Construction Management*, *16*(2), 150-160. https://www.tandfonline.com/doi/abs/10.1080/15623599.2015.1130602

Zhu, Y., Ding, J., Zhu, Q., Cheng, Y., Ma, Q., & Ji, X. (2017). The impact of green open space on community attachment—A case study of three communities in Beijing. *Sustainability*, *9*(4), 560. https://www.mdpi.com/2071-1050/9/4/560