INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
Vol. 12 No. 4 (2021) 73-84

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet
ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Building A Comprehensive Conceptual Framework for Material Selection in Terms of Sustainability in The Construction Preliminary Design Phase

Trong Hung Dinh[1*], Trung Hieu Dinh[2]

[1]Chemnitz University of Technology, Str. der Nationen 62, 09111 Chemnitz, GERMANY

[2]University of Transports and Communications Lang Thuong, Dong Da, Hanoi, VIETNAM

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2021.12.04.007
Received 10 September 2020; Accepted 23 June 2021; Available online 29 December 2021

Abstract: Construction projects consume a massive amount of renewable and non-renewable resources and negatively affect sustainable development. The selection of materials is necessary to meet the demands of sustainability. The preliminary design phase is essential within construction project phases because the main requirements, budget, and master drawings are planned here. Also, the selection of primary materials is considered in this phase. However, the integration of material selection and sustainability in the preliminary design phase has been underestimated. This paper reviewed sustainability in the preliminary design phase and the importance of material selection in accordance with sustainability in this phase. By using current literature and tools like Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM), the paper establishes a conceptual framework including sub-aspects that relate to sustainable aspects (economy, environment, and society). The proposed sub-aspects, such as total cost, cost efficiency, budget management, and water efficiency, define the relevant activities that help select the most sustainable materials. The results can be applied as a guide to decision-makers and promote sustainability right from the preliminary design phase. Future studies may provide methods for each criterion and establish a detailed plan to apply this framework in practice.

Keywords: Conceptual framework, material selection, sustainability, preliminary design phase

1. Introduction

Construction projects consume an abundance of raw materials and energies, threatening resources for future generations. Indeed, the construction industry depletes 40% of natural materials, consumes 40% of the energy and 15% of freshwater resources, generates 25% of all waste, and emits 40-50% greenhouse gas (Ramesh et al., 2010, Mokhlesian and Holmén, 2012). Bribián et al. (Bribián et al., 2011) found out that construction products are responsible for 24% of global materials such as water, mineral, and fuel. Franzoni et al. (Franzoni, 2011) agreed with this issue by pointing out that a large number of rare and non-recovery materials are used in construction projects. They also concluded that material selection plays a vital role in reaching goals of sustainability. Construction processes request many resources, labors, and equipment, which leads to tremendous challenges, represented by carbon emission or resource depletion, and puts pressure on sustainability efforts. The long-term issues, such as resource depletion and environmental pollution, have consecutively highlighted conspicuous profits of sustainability in the construction industry. Sustainable development is a way of confirming that all construction works are being executed in a sustainable way, from the planning phase to the demolition

*Corresponding author: hungdt0208@gmail.com

phases (Ismail et al., 2017), since construction activities directly impact on the economy, environment, and society (George et al., 2012, Aghimien et al., 2019), and have more significant effects on sustainable development in comparison with other sectors. Hence, it is rather compulsory to select the proper materials to integrate sustainability into the whole construction project. John et al. (John et al., 2005) discussed that conscientious material selection is the most effortless way to incorporate sustainable principles in the construction area. For example, by using recovered materials, the extent of negative environmental impacts decreased, and along with that, the sustainability level may be fostered.

The preliminary design phase is a part of the Planning and Design phase to prepare the most required documents, such as schematic design schemes, expected budget, and dimensioned space layout. That is to say, it transforms project goals and specifications into plans, drawings and reports. Rockizki and Peggy (Rockizki and Peggy, 2013) concluded that the preliminary design phase is a crucial part of the project because the main requirements and specifications are planned. Sustainability needs to be applied in the preliminary design phase(Feria and Amado, 2019).

The research community has not noticed the integration of sustainability and material selection in the preliminary design phase. Deng and Edwards (Deng and Edwards, 2007) studied the role of material selection in the early design phase. They pointed out that this selection is an inevitable issue due to fewer tools and technique supports than the later stages of the design phase. The importance of material selection in the preliminary design phase was certified by Rockizki and Peggy (Rockizki and Peggy, 2013). However, they also indicated that this phase's current material selection approaches were mostly in conformity with the mechanical engineering aspects rather than combining sustainability. Similarly, Li and Guo (Li and Guo, 2015) suggested that material selection needs to obey sustainability principles to make the construction valuable during in-construction and after-construction periods.

According to the issues mentioned above, the material selection based on sustainability in the preliminary design phase has been overlooked, leading to a lack of guidelines and technique supports. This paper aims to provide an overview of material selection based on sustainability in the preliminary design phase and establish a comprehensive conceptual framework for material selection based on sustainability in the preliminary design phase. This framework is built according to current studies in keeping with supporting tools of the later design phase, such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM).

2. Literature Review

2.1. Construction Phases

It appears that a construction project is divided into six phases, including initiation, planning and design, tender/bidding, construction, handover and operation, and close-out (figure 1).

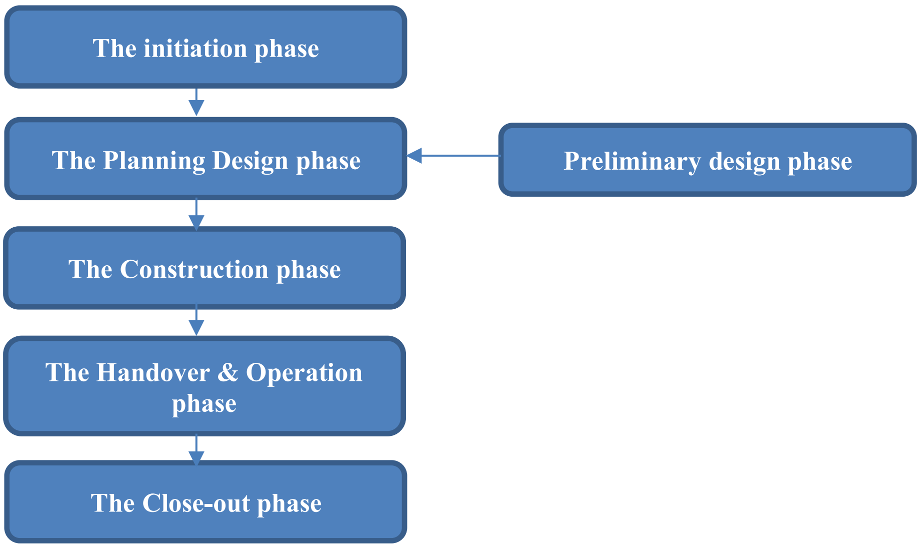

Fig. 1 - The construction phases

The initiation phase defines the project scope and its requirements. The scope gives information about project targets, technical specifications, location, a required construction type, and team members. Moreover, project requirements are created on the basis of technical standards, economic standards, society standards, environmental standards, and other standards (Griffin, 2010).

The road structure, implementation plan, construction workload, materials, necessary cost are identified for the planning and design phase. The designing phase comprises pre-design, preliminary design, and detailed design steps. The pre-design step establishes *detailed project design criteria,* such as its budget, environmental influences, and other requirements, which manage project design. After defining the criteria, designers complete *the preliminary design,* including construction area surveys, reviews of construction conditions, primary materials as well as completed sketches (Klinger and Susong, 2006). Detailed designs completed on the ground of agreed preliminary designs are sent to legal experts to examine and review (Pfeifer, 2009). The planning provides *a specific master schedule and budget allocation plan* containing information about construction time, starting date, work relationships, and work procedure (De Marco, 2014).

The best contractors are chosen based on specific criteria like tender price, experience of bidders, and qualification of bidders for the tender/ bidding phase. After that, the construction phase continued includes pre-construction, construction, and construction management. The owners get a building permit, handover construction site, and prepare the construction budget in the *pre-construction phase*. Concurrently, the selected contractor mobilizes laborers, machines to the construction area and finds material suppliers responsible for providing materials at the right time, the right place, the right price, the right condition, and the right quantity (Sullivan et al., 2011). The contractor converts construction drawings, along with resources, such as materials, energies, labors, and equipment, to build the construction product during the *construction* period (Harris and McCaffer, 2013). The construction management manages the schedule, quality, cost, environmental impact, and safety utilizing the information within the project structure drawing, actually completed works, and schedule planning (Wilson, 2014).

The next one is the handover & operation phase, in which the construction product has its full functions and hand over to the sponsor or owner. The construction quality is determined based on operational time, maintenance, fixing, and broken parts replaced. If the most valuable materials are chosen in the design phase, the operational time lasts longer, and the number of materials for fixing and replacing will be reduced.

The owner will re-evaluate the construction's quality in the close-out phase. If it does not meet the quality requirement, a new construction project is initiated to replace the old one. On the contrary, it will continue to be operated and be monitored carefully.

2.2. The Preliminary Design Phase

The preliminary design phase, also known as schematic design, refines the conceptual design phase requirements. This phase is responsible for the preparation of all essential documents to operate the construction project. It transforms ideas and requirements into plans, drawings, and specifications that are appraised by the owners. Bennet (Bennett, 2003) displayed the main tasks and documents followed by stakeholders during this phase. For example, architects deal with accomplishing preliminary designs, and engineers worry about how various systems may fit into the whole project. Winkler and Chiumento (Winkler and Chiumento, 2009) determined the preliminary phase as a phase where the most valuable schematic design schemes are developed in more detail to define the design site, structure, test fit, and budget. Kendira et al. (Kendira et al., 2011) suggested that a typical construction project embraces four main phases: pre-design, design, construction, and furnish or move-in phases. Moreover, the design phase continues falling under categories such as schematic development, preliminary design, and working drawings. The preliminary design phase completes the dimensioned space layout, structures, HVAC systems, utility and specific requirements, and the preliminary cost.

Andrade et al. (Andrade et al., 2012) divided the design phase into the conceptual, pre-design, and detailed design stages. They defined the conceptual phase as the preliminary design phase that illustrates overall system configuration, schematic drawings, schedule, type of critical structures, materials, and budget. Ottosson (Ottosson, 2012) concluded that a construction project follows specific processes, including Project initiation, project planning, and project implementation (design, building, testing, and guarantee period). The preliminary design phase is a part of project design implementation to establish technical documents, aesthetic designs, principal layout, scope and detail of systems, budget, and principal drawings. Rockizki and Peggy (Rockizki and Peggy, 2013) detected that the preliminary design phase is a foremost part of the project's success because the main requirements, such as budget, functional demands, and expected product performance, are planned here.

The design phase is divided into schematic design, preliminary design, and design development by Fandino et al. (Fandino et al., 2015). They also listed the preliminary design phase tasks involving deciding the characteristics of functions, structures, and materials, defining graphical representation, dimensional information, and spatial proposal. A traditional construction process, as suggested by Rumane (Rumane, 2016), includes Conceptual Design, Preliminary Design, Detail Engineering, Construction, and Commissioning and Handing Over. In the preliminary design phase, the designers are responsible for developing the general layout, facility scope, budget, main materials, schedule, contract terms and condition, and project regulatory approval. Similarly, Feria and Amado (Feria and Amado, 2019) noted that the preliminary design phase sets out to realize the main structure, main materials, internal layouts, required elements, and additional facilities.

2.3. Sustainability in The Preliminary Design Phase

The preliminary design phase serves as a constituent of the design phase, and its interconnection with sustainability has been researched in several studies. Besides clarifying design phases, Andrade et al. and Bragança et al. (Andrade et al., 2012, Bragança et al., 2014) set out sustainability indicators for early design phases that contain core indicators (economic and environmental indicators) and additional indicators (economic, social and environmental indicators). They also suggested that the preliminary design phase only uses core indicators, while additional ones are applied later. It means that the social indicators are almost neglected in this phase.

The National Institute of Building Sciences (National Institute of Building Sciences [NIBS], 2014) and Li and Guo (Li and Guo, 2015) agreed that sustainability principles should be applied from the preliminary design phase. In other words, the concepts and principles of sustainability, coupled with triple bottom lines (economic, social, and environmental dimensions), need to be included in making decisions in the preliminary design phase.

Pankovska et al. (Pancovska et al., 2017) analyzed the elements impacting the preliminary design phase's sustainable assessment and built a model for predicting the sustainability assessment. They also confirmed that the preliminary design phase plays the most critical role in sustainable development decisions. In this study, the data were garnered from a survey questionnaire utilizing a six-point Liker scale and general regression neural network to select and rank 27 factors that are most likely affect sustainable assessments in the preliminary design phase. In conclusion, the results revealed the six most essential factors, involving work experience, working on several outline design proposals, resolving stakeholders' issues, prioritizing participants in the design phase, procurement management, and defining projects' programs and goals.

Gültekin et al. (Gültekin et al., 2018) contextualized sustainable building design in a comprehensive theoretical framework regarding dimensions, strategies, criteria, and procedures in order to establish an economic, social, and environmental awareness on how to design sustainable construction products. They set up environmentally, economically, and socially sustainable building design, including criteria and procedures applied in the design phases. In 2019, Feria and Amado (Feria and Amado, 2019) published a paper discussing the potential of integrating sustainability into the architectural design phase. They confirmed that the sustainability principle needs to be covered every stage of the design phase because their outcomes influence the whole product life cycle.

2.4. Material Selection in Terms of Sustainability in The Preliminary Design Phase

Material selection contributes to the preliminary design phase, an early step in the design phase. Graedel et al. (Graedel et al., 1995) presented a term of "green design" or "design for environment," including generic and specific activities. Generic activities are explicit instructions for environmentally favored approaches, such as minimizing natural resource consumption, while particular activities are in charge of individual objects, such as material selection. Besides, they still determined that material selection should be applied during the product life cycle. Deng and Edwards (Deng and Edwards, 2007) pointed out the role of material identification and selection in the design phase. They confirmed that the material selection is a critical issue in the early design phase, which has fewer tools and technique supports than the later stages of the design phase. They also categorized material-related decision-making activities into material identification, material selection, and material design. The material identification serves as a constituent of the early design phase to identify the primary potential materials contributing to the fulfillment of required functions. The study revealed that the research community did not fully pay attention to the material-related activity and integration of the product life cycle in the early design phase.

The importance of material selection in the preliminary design phase was confirmed by Rockizki and Peggy (Rockizki and Peggy, 2013). This phase impacts on the product's performance by setting up the main structures, materials, budget, and project requirements. However, they pointed out that the current material selection approaches in this phase were mostly in conformity with the mechanical engineering aspects rather than combining sustainability. They also exerted to touch on the combination of environmental aspects into the material selection. However, it encounters many obstacles in this phase, including the unavailable information, different environmental profiles, environmental impact quantification, and product life cycle. This study has not yet touched on the social assessment for material selection in the preliminary design phase. As suggested by Li and Guo (Li and Guo, 2015), material selection serving as a part of the preliminary design phase needs to conform with sustainability principles to make the construction sustainable during in-construction and after-construction periods.

In conclusion, a cluster of studies still struggles to integrate sustainability into material selection in the preliminary design phase because of the lack of accessible information, tools, and data. Most of these researches solely focus on the economic and environmental aspects rather than triple bottom lines. That being the case, it is essential to initiate a comprehensive conceptual framework assessing the economic, environmental, and social dimensions altogether for selecting construction material in the preliminary design phase.

3. Materials and Methods

The proposed framework is established based on the current literature, which focuses on the sustainability criteria. The research was conducted in the scientific databases Scopus and ISI Web of Science, with the keywords "sustainability criteria," "construction," and "design phase." The selected papers need to be reviewed in a double-blind review process and focus on two main contents: sustainability criteria and the construction design phase. After that, the potential criteria were reviewed to find out which is suitable for the preliminary design phase, and then the framework was built, including criteria, activities, and advantages.

Besides, the supporting techniques were also reviewed, such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and the Guidelines for Social Life Cycle Assessment of Products to select potential criteria. The Building Research Establishment (BRE) developed *BREEAM* to assess the sustainability of infrastructure and buildings. It guides designers, researchers, and related stakeholders to effectively use resources through the product life cycle of new construction and refurbishment. The construction products are then labeled as pass, good, very good, excellent, and outstanding certificates. *LEED system* was developed by the US Green Building Council (USGBC) to label buildings as platinum, gold, silver, and certified certificates. It is a system identifying that the construction product is healthier, more environmentalist, and more economical than traditional ones, so as to mark it as a high-performance building and sustainable neighborhood. It builds a framework to measure health, efficiency, environmental impacts, and cost-saving of buildings. It is to say that it reveals sustainable designs, construction, and operation criteria. *The Guidelines for Social Life Cycle Assessment of Products* presents a map, a skeleton, and a flashlight to assess the product life cycle's social performance. The map describes the contexts, key concepts, and broader fields of social assessment. The skeleton presents key elements considered and guides the goal and scope, life cycle inventory analysis, life cycle impact assessment, and interpretation phases of a social life cycle assessment. The flashlight emphasizes areas where further studies are needed.

4. A Comprehensive Conceptual Framework for Selecting Materials Based on Sustainability in The Preliminary Design Phase

Material selection impacts all the economic, social, and environmental aspects, so considering sustainability from the preliminary design phase is essential. Initially, a comprehensive conceptual framework, based on existing studies, LEED, BREEAM, and actual costs, is built to support the architects/designers in making material decisions in the preliminary design phase. This framework distinguishes three aspects: sustainable economic aspects, sustainable environmental aspects, and sustainable social aspects, in which the environmental and social aspects are cores of research. Sustainable economic aspects focus on the expected total cost, cost efficiency, and budget management; environmental aspects delve into site efficiency, water efficiency, energy efficiency, material efficiency, and toxic emission; social aspects dig into health, well-being, and stakeholder effects. Table 1 depicts the aspects, sub-aspects, and criteria of the proposed comprehensive conceptual framework.

Table 1 - Aspects, sub-aspects, and criteria of the proposed comprehensive conceptual framework

Aspects	Sub-aspects	Criteria
Sustainable economic aspects	Total cost	Costs throughout the life cycle
	Cost efficiency	Potential cost reduction
	Budget management	Manage the expected budget
Sustainable environmental aspects	Site efficiency	Protection of natural topography
		Improvement of transportation systems
		Reduction of the heat island effect
	Water efficiency	Reduction of water consumption
		Reuse of wastewater
	Energy efficiency	The use of heating, ventilating, and air conditioning
		Utilization of daylighting
	Material efficiency	Reduction of environmental impacts
		Reduction of wastes
		Proper sizing of building and systems
	Toxic emission	Reduction of toxic emission
		Treatment of toxics
Sustainable social aspects	A suitable method	Flexible application and easy-to-use method
		Available database
	Impacts of stakeholders	Workers
		Consumers
		Local community
		Society
		Other actors of the value chain
	Health and well-being	Livable environment
		Contribute to the public in the long future

4.1. Sustainable Economic Aspects

Sustainable economic aspects include many criteria and relevant activities responsible for estimating and controlling the expected material cost. To aim the sustainable target, the initial cost may be higher than the one from conventional construction. However, the life cycle cost could be lower than the costs of typical construction due to reduced annual costs. Moreover, the reduction costs stemming from local, reclaimed, and recycled materials, could be considered as indirect economic benefits. Sustainable economic aspects are classified into the total cost, cost efficiency, and budget management.

Total Cost

Costs during the life cycle need to be considered in order to estimate the total material cost. The Life Cycle Costing method could be applied to spread over all stages of the project life cycle and consider the material-dependent costs. This method may measure the material cost from the beginning of the design phase, thanks to the available economic databases (Fusaro et al., 2019). In addition, the material-dependent costs are also considered to boost the completeness. Table 2 represents the activities and advantages of the total cost sub-aspect.

Table 2 - Activities and advantages of the total cost sub-aspect

Criteria	Activities	Advantages
Costs throughout the life cycle	Define the Life cycle of main materials and their cash flows	Define the material costs throughout the life cycle
	Define the material-dependent cost	Define the material-dependent cost of selected materials

Cost Efficiency

The activities of cost efficiency focus on long-term economic benefits and potential cost reduction in virtue of decreasing the potential costs during the material life cycle. LEED system encourages recycled, reclaimed and local materials in green building design as a way of cost reduction (Krueger et al., 2019). The use of recycled materials increases the indirect economic benefit while selecting local materials and reclaimed materials minimizes shipping costs and remanufactured costs. The easy-to-use materials reduce costs in the construction phase and enhance the construction value (Samosir et al., 2020), and the warehouse location is a crucial determinant of internal transportation cost since the travel time was reduced (Tagliabue et al., 2020). Flexible materials and relevant construction technology reduce costs in the construction phase, while standard, common, and available materials help reconfiguration convenient when required (Gültekin et al., 2018). The activities and corresponding advantages are completely illustrated in table 3.

Table 3 - Activities and advantages of the cost efficiency sub-aspect

Criteria	Activities	Advantages
Potential cost reduction	Use local materials	Reduce shipping costs
	Use easy-to-use materials	Reduce costs in the construction phase
	Use recycled materials	Increase indirect economic benefits
	Use reclaimed and reused materials	Reduce reprocessed costs
	Location of warehouse	Reduce internal transportation cost in the construction site
	Use standard, common and available materials	Reduce costs for changing designs
	Select flexible materials and relevant construction technology	Reduce costs in the construction phase.
	Select long-enduring and high-quality materials	Reduce costs in the operation phase
	Consider the ease of demolition of materials	Reduce costs in demolition.
	Shorten the construction time of materials	Reduce the costs in the construction phase
	Restrict the changes in designs	Reduce the changes in material cost

Budget Management

The preliminary design phase submits the project budget, so the budget management should not shy away from the proposed framework. This management sets its sights on managing and controlling the budget effectively by activities in table 4. The key milestones are established to predict the actual material costs between two consecutive milestones, while a suitable communication manner supports actual material costs. Finally, the main risk prediction paves the way in controlling the redundancy costs of selected materials.

Table 4 - Activities and advantages of the budget management sub-aspect

Criteria	Activities	Advantages
The expected budget management.	Defined main project milestones	Forecast the actual material costs in each period
	Build communication ways between stakeholders (e.g., BIM)	Support the management of actual material costs
	Predict the main risks	Control the redundancy costs of selected materials

4.2. Sustainable Environmental Aspects

Sustainable environmental aspects contain criteria and relevant activities for estimating and comparing environmental performance. The site efficiency, water efficiency, energy efficiency, material efficiency, and toxic emission are covered by environmental aspects to meet sustainable demands.

Site Efficiency

The process of urbanization leads to a rapid increase in construction demand. However, because of the limited land area, it requires the use of existing land effectively. Effective land use complies with the following requirements: Protection of the natural topography, Improvement of transportation systems, Reduction of heat island effect. The decision-makers use metal troughs, tar ditches, green materials, and technical-required soil to protect natural topography. For example, instead of using concrete piles, designers can consider using bamboo piles, cajuput piles with similar effect in wetlands and soft ground (Sharma et al., 2014). The improvement of transportation systems can be reached by using modern high-quality materials, finding many suppliers, and locating the warehouse near the construction site. The activities and advantages of site efficiency sub-aspect are illustrated in table 5.

Table 5 - Activities and advantages of the site efficiency sub-aspect

Criteria	Activities	Advantages
Protection of natural topography	Use metal troughs or tar ditches	Effective drainage treatment
	Use bamboo piles, cajuput piles in wetlands	Interacting well with the surrounding environment
	The soil used for leveling must meet technical requirements and be local	Benefit of creating paths and roads
Improvement of transportation systems	Use modern, high-quality materials	Easily convert paths into roads when the projects are nearly finished
	Buy major parts materials from a few main local suppliers	Better transportation and management
	Organize the warehouses on the construction site	Better transportation and management
Reduction of the heat island effect	Use heat resistant construction materials like Low-E glass	Balance the temperature inside buildings, reduce the urban heat island effect

Water Efficiency

Water is essential for human life, but clean water resources are limited; thus, protecting the resource is vital. In this context, water efficiency criteria are classified as the reduction of water consumption and the reuse of waste water. Special attention must be given to the reduction of water consumption in the preliminary design phase by selecting the near water supplier or quality water pies. Moreover, rainwater, a kind of waste water (Zavala et al., 2018), can be stored and reused. Table 6 illustrates the activities and advantages of the water efficiency sub-aspect.

Table 6 - Activities and advantages of the water efficiency sub-aspect

Criteria	Activities	Advantages
Reduction of water consumption	Select quality water pipes	Avoid leakage
	Select water supplies near construction site	Save pipes and quickly supply water
Reuse of waste water	Reuse rainwater	Saving water
	Use waste water treatment systems with natural ingredients: sand, stones, algae	Easy to make, being environmental-friendly

Energy Efficiency

Energy consumption increases approximately 5% every year, mainly because of industrialization, rapidly growing population, and improvement in the living standards (Gültekin and Farahbakhsh, 2014). The increasing consumption of fossil fuel gives rise to the ozone layer depletion, air pollution, and climatic change (Florinda Martins, 2019). Therefore, efficient utilization of energy has become crucial in the construction sector and consists of the use of heating, ventilating, air conditioning, and utilization of daylight. Table 7 shows the activities and advantages of the energy efficiency sub-aspect.

Table 7 - Activities and advantages of the energy efficiency sub-aspect

Criteria	Activities	Advantages
The use of heating, ventilating, and air conditioning	Use insulation material	Avoid heat/cold vapor loss
	The appliance that consumes less electricity or fossil fuel should be considered	Saving energy
Utilization of daylighting	Use low-E glasses	Balance the temperature inside buildings, get natural light

Material Efficiency

The building materials' production and consumption have impacts on local and global environments. The material efficiency criteria relate to reducing the environmental impacts and construction wastes through the entire life cycle of building materials. Construction works have a close relationship with the environment, so it is necessary to encourage the selection of natural materials such as laminated wood and bamboo pipes. Besides, the preservation of materials must be taken care of to avoid loss, wind or rain, and applying the latest material-using norms and 3-D printing technology to help material consumption efficient and eco-friendly. Selecting reusable, recyclable, recycled building materials like unburnt fly ash bricks also contributes to waste reduction. Table 8 depicts the activities and advantages of the material efficiency sub-aspect.

Table 8 - Activities and advantages of the material efficiency sub-aspect

Criteria	Activities	Advantages
Reduction of environmental impacts	Encourage the selection of natural materials, recycled materials	Protect the environment and habitat
	Manage the preservation of materials	Avoid leakage
	Update norms	Ensure maximum material saving, to use advanced construction machines and methods to limit the material loss
	Utilize 3-D printing technology	Manage the consumption of natural material in the construction field
Reduction of wastes	Select reusable, recyclable, recycled building materials like unburnt fly ash bricks	Reduce the exploitation of natural resources

Toxic Emission

Construction activities release a number of toxic substances into the environment: waste oil, vehicle exhaust gas, water for cleaning materials and vehicles (Pacheco-Torgal, 2012). The proposed framework emphasizes the reduction of toxic emission and the toxics' treatment. The toxic emission reduction is obtained by avoiding toxic leakage out or limiting poisonous substances. The toxics should then be treated according to a basic principle: handling toxic but not adding more harmful to the environment. Activities and advantages of the toxic emission sub-aspect are depicted in table 9.

Table 9 - Activities and advantages of the toxic emission sub-aspect

Criteria	Activities	Advantages
Reduction of toxic emission	Avoid toxic leakage out	Protect the environment
	Try to limit using toxic	Protect the human's health and the environment
Treatment of toxics	Use natural materials for treatment	Not adding more toxic to the environment

4.3. Sustainable Social Aspects

Sustainable social aspects have not yet touched on in the preliminary design phase (Andrade et al., 2012, Bragança et al., 2014); notwithstanding, it does not imply that these aspects are abandoned because it is still a part of sustainability. To put it another way, they specified that environmental and economic aspects could be evaluated in a more facile manner compared to the social aspect, as they require less information for this phase than the social one. In this study, the scheme for sustainable social aspects is grouped into a suitable method, impacts of subcategories, and health and well-being.

A Suitable Method

The preliminary design phase needs a supporting method to evaluate the social dimension of material selection. This method should be referred to as a flexible application and easy-to-use method as well as an available database (table 10). A flexible application could fit various materials, while an easy-to-use method makes the application straightforward. The preliminary design phase is only granted with a limited amount of time to come up with decisions, so the selected method should take not much time to calculate and be accepted by the community. This phase is also subject to the shortage of database, so the method should bother the existing database or is capable of building the required data.

Table 10 - Activities and advantages of the suitable method sub-aspect

Criteria	Activities	Advantages
Flexible application and easy-to-use method	Define a flexible application	Fit all kinds of materials
	Select an easy-to-use method	Easy to apply in practice
	Not much calculation time	Shorten calculation time
	Select an agreed method	Prevent arguments
Available database	Existing database	Prevent a lack of database
	Build new data straightforwardly	Set up demanded data

Impacts on Stakeholders

United Nations Environment Programme (United Nations Environment Programme and Chemistry, 2009) established a guideline to assess the social aspects of products. This guideline identifies stakeholders who should be effectively and efficiently engaged in improving the production's social and socio-economic conditions. The stakeholders are categorized into workers, the local community, society, consumers, and other value chain actors. The relevant activities are suggested by the United Nations Environment Programme (table 11).

Table 11 - Activities and advantages of the impacts on stakeholders sub-aspect

Criteria	Activities (Consideration)	Advantages
Worker	Freedom of association and collective bargaining	Define the potential of joining a union
	Child labor	Prohibit the child labors
	Fair salary	Equal salaries
	Working hours	Reduce the working overtime
	Forced labor	Prohibit Forced labors

	Equal opportunities/discrimination	Confirm Equal opportunities/ discriminations
	Health and safety	The health and safety of the labors
	Social benefits/social security	Ensure the social benefits
Consumer	Health and safety	The health and safety of the consumers
	Feedback mechanism	Get feedbacks from stakeholders
	Consumer privacy	Protect the consumer benefits
	Transparency	Supervise easily
	End of life responsibility	The responsibility of stakeholders
Local community	Access to immaterial resources	Promote community services
	Delocalization and migration	Prevents involuntary resettlements
	Respect of indigenous rights	Adapt indigenous rights
	Community engagement	Define the environment, health or welfare of a community
	Local employment	Use local labors
Society	Prevention and mitigation of armed conflicts	Prevent the mitigation
	Technology development	Promote the technology
	Corruption	Prohibit the corruption
Other value chain actors	Fair competition	Confirm anti-trust legislation, or monopoly practices
	Promoting social responsibility	Promote the social responsibility
	Supplier relationships	Define a code of conduct with defined standards of ethical behaviour expected from its suppliers
	Respect of intellectual property rights	Ensure the intellectual property system

Source: (United Nations Environment Programme and Chemistry, 2009)

Health and Well-Being

The quality life enhancement and public contribution should be paid attention to in the framework. The quality of life could be reached by preventing pollution, considering disabled users' accessibility, and using healthy materials. The contribution to the public is covered by the ability to prolong the operation phase. Table 12 shows the activities and advantages of the health and well-being aspect of the proposed framework.

Table 12 - Activities and advantages of the health and well-being sub-aspect

Criteria	Activities	Advantages
Livable environment	Prevent pollution in using phase	Reduce toxic pollutants in the using phase.
	Consider the accessibility of disabled users	Ensure social equity
	Provide air quality, thermal, visual, and light (HVAC system)	Improve the living standard
	Use healthy/nontoxic materials	Prevent disease
Contribute to the public in the long future	Predict the ability to prolong the operation phase	Contribute to infrastructure networking and economic development.

5. Conclusion and Future Works

Integrating sustainability into the construction industry brings many benefits in terms of economic, environmental, and social issues to the future generation. The preliminary design phase puts in charge of the most important decisions concerning construction projects' sustainability. In addition, material selection is the most straightforward way of applying sustainability to construction projects. Therefore, this paper identified the position and roles of the preliminary design phase, together with the integration of material selection and sustainability into this phase, so as to find out the challenges and obstacles. The study clarified that the integration of sustainability and material selection in the preliminary design phase was not taken notice of the research community because of the absence of guidelines and supporting tools. The current sustainable assessment methods fit on the later design phases rather than the preliminary design phase.

Accordingly, a comprehensive conceptual framework for material selection in terms of sustainability in the preliminary design phase was established. The proposed framework is established according to current studies and supporting methods, such as BREEAM or LEED. It covers three sustainability pillars, including economic, environmental, and social dimensions. The framework comprises criteria, activities, and advantages to show the decision-makers on how to select the most sustainable materials right from the early design phases. The economic aspects focus on the total cost, cost efficiency, and budget management. The social ones make an attempt to clarify method selection, impacts of stakeholders, and health and well-being, while environmental dimensions dig into criteria for site efficiency, water efficiency, energy efficiency, material efficiency, and Toxic emission.

This framework contributes to the improving literature on sustainable material selection in terms of economic, social, and environmental aspects in the preliminary design phase. It can be applied as an instruction for decision-makers and promotes sustainability in the construction industry. Future studies can come up with specific methods for each criterion and create a detailed plan to apply this scheme in practice.

Acknowledgement

The authors would like to thank and acknowledge Chemnitz University of Technology for all kind of supports.

Reference

AGHIMIEN, D. O., AIGBAVBOA, C. O. & THWALA, W. D. 2019. Microscoping the challenges of sustainable construction in developing countries. *Journal of Engineering, Design and Technology*.

ANDRADE, J. B., VIEIRA, S. A. M. & BRAGANÇA, L. 2012. Selection of key sustainable indicators to steel buildings in early design phases.

BENNETT, F. L. 2003. *The management of construction: a project life cycle approach*, Routledge.

BRAGANÇA, L., VIEIRA, S. M. & ANDRADE, J. B. 2014. Early stage design decisions: The way to achieve sustainable buildings at lower costs. *The scientific world journal,* 2014.

BRIBIÁN, I. Z., CAPILLA, A. V. & USÓN, A. A. 2011. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and environment,* 46**,** 1133-1140.

DE MARCO, A. 2014. *Project management for facility Constructions*, Springer.

DENG, Y.-M. & EDWARDS, K. 2007. The role of materials identification and selection in engineering design. *Materials & design,* 28**,** 131-139.

FANDINO, J., CASTRO-LACOUTURE, D. & ARANGO, D. 2015. Incorporation of LEED criteria into architectural design process: a strategy to increase construction quality. *WIT Transactions on Ecology and the Environment,* 194**,** 179-189.

FERIA, M. & AMADO, M. 2019. Architectural Design: Sustainability in the Decision-Making Process. *Buildings,* 9**,** 135.

FLORINDA MARTINS, C. F., MIROSLAVA SMITKOVA, NÍDIA CAETANO 2019. Analysis of Fossil Fuel Energy Consumption and Environmental Impacts in European Countries. *Energy Procedia,* 153.

FRANZONI, E. 2011. Materials selection for green buildings: which tools for engineers and architects? *Procedia Engineering,* 21**,** 883-890.

FUSARO, R., VIOLA, N., FERRETTO, D., VERCELLA, V., VILLACE, V. F. & STEELANT, J. 2019. Life cycle cost estimation for high-speed transportation systems. *CEAS Space Journal***,** 1-21.

GEORGE, A., ANDREW, K. & CHRISTOPHER, C. 2012. 4Es and 4 Poles model of sustainability-Redefining sustainability in the built environment. *Structural Survey,* 30**,** 426-442.

GRAEDEL, T. E., COMRIE, P. R. & SEKUTOWSKI, J. C. 1995. Green product design. *AT&T technical journal,* 74**,** 17-25.

GRIFFIN, J. A. 2010. *Residential construction management: Managing according to the project lifecycle*, J. Ross Publishing.

GÜLTEKIN, A. & FARAHBAKHSH, E. 2014. *Evaluation of the Energy Performance of Glass Construction Materials in Turkey*.

GÜLTEKIN, A. B., YıLDıRıM, H. Y. & TANRıVERMIŞ, H. 2018. A Holistic Conceptual Scheme for Sustainable Building Design in the Context of Environmental, Economic and Social Dimensions. *Sustainable Buildings: Interaction Between a Holistic Conceptual Act and Materials Properties***,** 19.

HARRIS, F. & MCCAFFER, R. 2013. *Modern construction management*, John Wiley & Sons.

ISMAIL, F. Z., HALOG, A. & SMITH, C. 2017. How sustainable is disaster resilience? *International Journal of Disaster Resilience in the Built Environment*.

JOHN, G., CLEMENTS-CROOME, D. & JERONIMIDIS, G. 2005. Sustainable building solutions: a review of lessons from the natural world. *Building and environment,* 40**,** 319-328.

KENDIRA, A., GIDEL, T., JONES, A., LENNE, D., BARTHČS, J.-P. & MOULIN, C. Conducting preliminary design around an interactive tabletop. DS 68-2: Proceedings of the 18th International Conference on Engineering

Design (ICED 11), Impacting Society through Engineering Design, Vol. 2: Design Theory and Research Methodology, Lyngby/Copenhagen, Denmark, 15.-19.08. 2011, 2011.

KLINGER, M. & SUSONG, M. The construction project: phases, people, terms, paperwork, processes. 2006. American Bar Association.

KRUEGER, K., STOKER, A. & GAUSTAD, G. 2019. “Alternative” materials in the green building and construction sector. *Smart and Sustainable Built Environment.*

LI, X. & GUO, L. Study on civil engineering sustainable development strategy. 2015 International Conference on Management, Education, Information and Control, 2015. Atlantis Press.

MOKHLESIAN, S. & HOLMÉN, M. 2012. Business model changes and green construction processes. *Construction Management and Economics,* 30**,** 761-775.

NATIONAL INSTITUTE OF BUILDING SCIENCES [NIBS] 2014. *Whole Building Design Guide (WBDG),* Washington, DC, USA, National Institute of Building Sciences.

OTTOSSON, H. 2012. *Practical project management for building and construction*, CRC Press.

PACHECO-TORGAL, F. 2012. Introduction: types of potentially toxic building materials. *In:* PACHECO-TORGAL, F., JALALI, S. & FUCIC, A. (eds.) *Toxicity of Building Materials.* Woodhead Publishing.

PANCOVSKA, V. Z., PETRUSHEVA, S. & PETROVSKI, A. 2017. Predicting sustainability assessment at early facilities design phase. *Facilities.*

PFEIFER, M. 2009. *Materials enabled designs: The materials engineering perspective to product design and manufacturing*, Butterworth-Heinemann.

RAMESH, T., PRAKASH, R. & SHUKLA, K. 2010. Life cycle energy analysis of buildings: An overview. *Energy and buildings,* 42**,** 1592-1600.

ROCKIZKI, J. & PEGGY, Z. 2013. Material Selection for Eco-design. *Smart Product Engineering.* Springer.

RUMANE, A. R. 2016. *Quality management in construction projects*, Crc Press.

SAMOSIR, D. K. B. M., MURWANINGSARI, E., AUGUSTINE, Y. & MAYANGSARI, S. 2020. The benefit of green building for cost efficiency. *International Journal of Financial, Accounting, and Management,* 1**,** 209-219.

SHARMA, P., DHANWANTRI, K. & MEHTA, S. 2014. Bamboo as a building material. *International Journal of Civil Engineering Research,* 5**,** 249-254.

SULLIVAN, G., BARTHORPE, S. & ROBBINS, S. 2011. *Managing construction logistics*, John Wiley & Sons.

TAGLIABUE, L. C., VENTURA, S. M., TEIZER, J. & CIRIBINI, A. L. 2020. A Serious Game for Lean Construction Education Enabled by Internet of Things. *Ludic, Co-design and Tools Supporting Smart Learning Ecosystems and Smart Education.* Springer.

UNITED NATIONS ENVIRONMENT PROGRAMME & CHEMISTRY, S. O. E. T. A. 2009. *Guidelines for social life cycle assessment of products: social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable development*, UNEP/Earthprint.

WILSON, R. 2014. *A comprehensive guide to project management schedule and cost control: methods and models for managing the project lifecycle*, Pearson Education.

WINKLER, G. & CHIUMENTO, G. 2009. *Construction Administration for Architects*, McGraw Hill Professional.

ZAVALA, M. Á. L., PRIETO, M. J. C. & ROJAS, C. A. R. 2018. Rainwater harvesting as an alternative for water supply in regions with high water stress. *Water Supply,* 18**,** 1946-1955.