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Toward Sustainable Construction Using Wood Material

A Review of Indicator-based Sustainability Assessments

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Abstract – The largest consumer of resources and contributor to CO2 emissions is the industrial sector. Sustainable construction is an approach that addresses these issues. As a significant factor influencing energy consumption and emissions in the construction industry, there is a notable shift in the use of building materials towards those derived from natural sources. Wood, which has renewable properties and is a CO2 sink, is an alternative material to consider. The objective of this paper is to provide a critical analysis of the utilization of wood as a material in the context of sustainable construction. The paper is structured by a review of the relevant literature on the subject, obtained from various academic database sources. The paper outlines the meaning of sustainability and sustainable construction and reviews wood materials in supporting sustainable construction through existing indicators. The results show the important role of wood in supporting sustainable construction from social, economic, environmental, and technological aspects. Some disadvantages of wood materials are the focus of some literature by providing alternative solutions through technology, responsible management, and policy.

Keywords: *construction, material, sustainable, wood.*

I. Introduction

Climate change is a global issue and a concern for many sectors worldwide, caused by various environmentally unfriendly activities. One factor that triggers these changes is the increase in CO_2 emissions. The construction sector is a major contributor to the increase in CO_2 emissions (Chen et al., 2017; Wang & Feng, 2018). In addition to environmental impacts, the sector also faces social and economic impacts (Baglou et al., 2017; Zabihi et al., 2012) as its activities are closely related to pollution, waste generation, and resource consumption (Kaja & Goyal, 2023). The construction industry is the largest consumer of natural resources in the world (Ghaffar et al., 2020). The activities and impacts of the industrial sector have raised concerns about increasing environmental degradation as the greatest crisis threat today (Goldhahn et al., 2021).

The term 'sustainable construction' has emerged as a way for the construction industry to take responsibility for issues related to sustainability (R. C. Hill et al., 1994). An environmentally responsible approach is key to achieving sustainability goals in construction (R. C. Hill et al., 1994). However, sustainable construction essentially contributes not only from an environmental aspect, but also socially, economically, and even technologically (Thomas et al., 2023), which aligns with the objectives of sustainable development. Sustainable construction is an integrated and holistic approach to the construction industry to achieve the goals of sustainable development (Thomas et al., 2023; Van Nguyen, 2023)

The selection of materials in the construction process is an important step in achieving sustainable construction. Materials are one of the main inputs in construction activities and are the main component that determines construction costs (Ive & Gruneberg, 2000). The materials used in construction also affect emissions through processes such as processing and transport (Sandanayake, 2022). As a major consumer of raw materials, the use of materials contributes to the goal of sustainable construction (Baglou et al., 2017; Ding, 2014).

The use of renewable materials is beginning to be considered as an alternative to the use of fossil-based materials. Wood is one of the renewable resources that is starting to be considered. The renewable nature of wood and CO_2 storage is seen as an environmentally friendly and sustainable material (Goldhahn et al., 2021). The increased use of wood in the construction sector can potentially contribute to decarbonization (Churkina et al., 2020; Hepburn et al., 2019). Negative environmental impacts (especially greenhouse gases) can be reduced by using wood-based materials and components, thus supporting sustainability goals (Ximenes & Grant, 2013).

On the other hand, the use of wood materials poses a threat to the environment. The potential for increased utilization of wood products may result in a corresponding rise in demand for wood, which could have implications for the condition of forests and the social and environmental benefits they offer (Pasternack et al., 2022). Wood also has a negative perspective due to its disadvantages, such as lack of durability, need for maintenance, and aesthetic quality due to weathering (Viholainen et al., 2021).

Although many studies have shown that wood is a sustainable material, it also has some disadvantages that pose challenges to its use in construction. The question then arises as to whether and how the use of wood can support the goal of sustainable construction. This question arises because existing research examine wood utilization from an environmental or specific aspect but does not consider all aspects of sustainable construction. The purpose of this paper is to conduct a review based on existing literature regarding the role of wood materials in supporting sustainable construction. The review is based on sustainable assessment indicators that cover all aspects discussed in the literature. It begins by defining the universal meaning of sustainability, the meaning of construction, and sustainable construction, explaining the role of materials in the construction industry, how wood materials are used, and their role in supporting sustainable construction. The paper's final part discusses the role of wood materials in the construction industry and its development opportunities.

I. METHODOLOGY

The methodology used in this paper is a literature review derived from relevant academic literature from journal articles, proceedings, books, and other sources. The primary data source in this paper is academic databases, mainly Scopus and Google Scholar. This database was chosen because of its broad scope, which provides information on articles from a wide range of disciplines. Using keywords to retrieve and filter appropriate information is the strategy used. The words and word combinations in the key were chosen based on the paper's purpose and considering the comprehensive search results. Some of the keywords for the structure of this paper are sustainability, construction, sustainable construction, material in construction, sustainable material construction, wood, wood in construction/building, and sustainable wood construction. The keywords selected will retrieve results from the database and then be filtered to select the appropriate data. The filter is mainly based on the year of publication, which is limited to the last ten years. However, if the required data is not available in the last ten years published, the filter is relaxed to include the previous year's data. The data used were also selected after a review of the selected literature to determine its suitability for the discussion in this paper. Literature that was not relevant to the discussion was not selected to be part of the data that was used.

II. RESULTS AND DISCUSSION

A. Definitions and Concepts of Sustainability

The idea of sustainability emerged in The Ecologist's A Blueprint for Survival in 1972 and relates to future life (Basiago, 1995). Human survival is the ultimate goal of sustainability (Brown et al., 1987). It will always involve the human element and the use of nature because human survival cannot be separated from the use of nature (Cabezas et al., 2003). Sustainability is defined as the utilization of the vital functions of the biophysical environment without irreparable damage to the ecosystem (Bisk & Bołtuć, 2017; Chakravarty, 1991; Hueting & Reijnders, 1998) so that it remains available indefinitely to meet the needs of the present and future generations (Chakravarty, 1991; Department of Economic and Social Affairs, 2008). The structure and functioning of the human element - social, economic, and legal - must support the continuity of the structure and functioning of the natural element – biodiversity, biogeochemical cycles, and ecosystem trophic linkages (Cabezas et al., 2003). On the other hand, a stable human condition will minimize ecological disturbance, allow maximum conservation, and keep populations constant (Basiago, 1995). Therefore, sustainability can be achieved by managing the global economy and maintaining the Earth's healthy functioning (Chakravarty, 1991).

Combining economic and human components with maintaining, preserving, or improving the environment (economic, social, and natural) in development efforts is known as sustainable development (Bisk & Bołtuć, 2017; Du Plessis, 2002; Duran et al., 2015; Robert W. Kates, 2015). This concept of development emphasizes quality of life (social or cultural perspective) with a stable economy (economic perspective), the management and maintenance of ecosystems, and the survival of species (biological perspective)(Brown et al., 1987; Chakravarty, 1991). This integration will achieve long-term economic and environmental stability, the goal of sustainable development (Emas, 2015).

The role of technology in achieving sustainable development goals is a crucial consideration. Technology plays an important role in sustainability by extracting resources from the environment and transforming them to meet human needs (Cabezas et al., 2003). Developing technology, innovating, and creating breakthrough solutions are essential to achieving all sustainable development goals (Berawi, 2017). The relationship between technology and society is reciprocal: technological change gives rise to new social structures and practices, while social change creates novel technological requirements and contexts (Mulder et al., 2017). Innovative technologies can also increase environmental capacity and compensate for negative environmental impacts (Klarin, 2018), often bridging conflicting demands (Mulder et al., 2017). The flexibility of interaction between the four fundamental systems (economic, human, environmental, and technological) is seen as a key factor in achieving economic and social development and environmental balance (Duran et al., 2015). Therefore, sustainable development with specific scenarios, goals, and targets (Robert W. Kates, 2015) has economic, environmental, social, and technological indicators for achieving of its objectives (Cabezas et al., 2003). Fig. 1 shows the fundamental system concepts that can interact with each other to achieve the goals of sustainability.

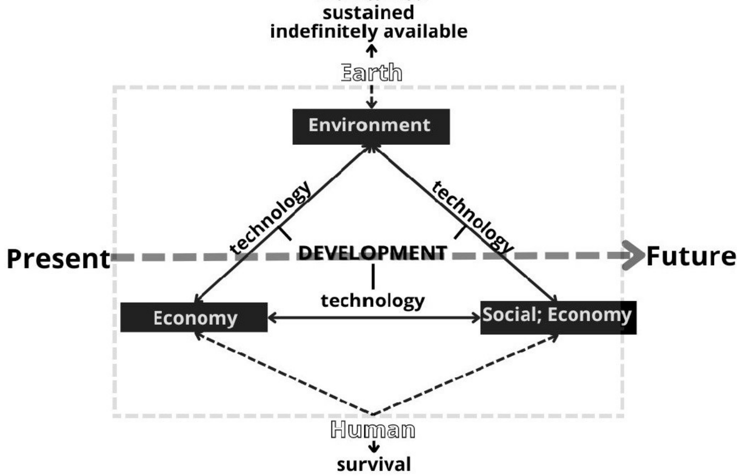

Fig. 1. The Fundamental System Concept of 'Sustainability'
Source: Authors (2024)

B. Sustainable Construction

Sustainable development, which includes environmental, social, economic, and even technological aspects, allows ‘sustainability’ to be implemented in various sectors that involve these aspects in their activities. In 1993, the European Union's Fifth Environmental Action Programme sought ‘sustainability’ in industry, energy, transport, agriculture, and tourism (Basiago, 1995). The construction industry has an integral role in sustainable development, given its responsibility to reduce buildings’ social, economic, and environmental impact and improve the quality of life (Baglou et al., 2017; Zabihi et al., 2012). As one of the sectors facing this challenge, the construction industry can influence positive change.

The application of the term construction to the physical realm, as used by Barry (1999), mainly focuses on building construction. Construction is an economic activity (Gruneberg, 1997; Moavenzadeh, 1978; Department of Economic and Social Affairs, 2008). Generally, there are three levels to define construction from narrow to broad (Pheng & Hou, 2019). The broadest definition is that construction refers to the entire process, from the initial stages of producing raw, manufactured building materials, and components to the final execution of physical works on site. This definition extends beyond the mere fabrication of physical work to encompass the provision of professional services such as project management and design (Gruneberg, 1997). In intermediate definition, construction refers to all activities that contribute to the creation of a specific type of object, such as buildings and other fixed structures, from conception and design to execution (Ive & Gruneberg, 2000; Moavenzadeh, 1978) as a comprehensive project cycle (Du Plessis, 2007). In the narrowest definition, construction is understood as an economic activity that encompasses solely the final stage, namely the physical work conducted at the production site (Department of Economic and Social Affairs, 2008), so it is only one of the process stages (Sinopoli, 2010). Fig. 2 illustrates the definition. The blue color is the broadest definition, while the yellow color is the narrowest definition. The purple color is the in-between definition.

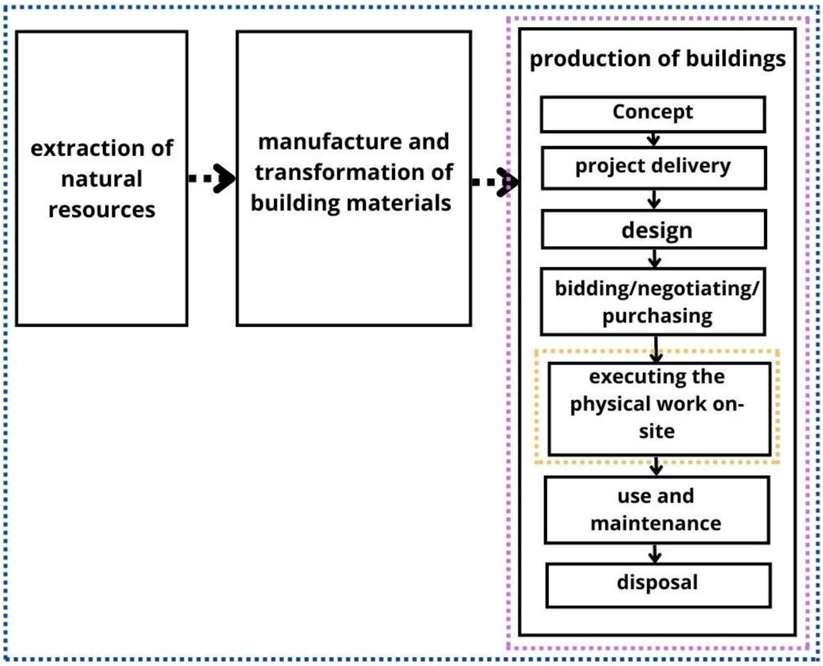

Fig. 1. Definition of Construction
Source: Authors (2024)

The increasing global focus on sustainability has led to a major drive to achieve sustainable development, putting pressure on the building industry to practice sustainable construction. Sustainable construction was proposed to describe the construction industry’s responsibility towards sustainability issues (R. C. Hill et al., 1994). Construction activities are closely related to environmental pollution and degradation, including waste, noise air pollution, and also resource consumption (Kaja & Goyal, 2023). The impact on nature, society, and economic development has prompted construction industry companies to address and report on their contribution to sustainable development driven by instrumental or social/political motives (Cortés et al., 2023).

Sustainable construction (SC) is a constructive process incorporating sustainable development's primary objectives: environmental responsibility, social awareness, and economic profitability (Liu et al., 2020). SC is described in more detail as a construction approach/practice based on an integrative and holistic 'circular' concept, which is socially acceptable, economically affordable, environmentally friendly, and technologically reliable and contributes to sustainable development (Thomas et al., 2023; Van Nguyen, 2023). Labor, people, materials, and equipment are the main inputs in the construction industry (Pheng & Hou, 2019), and its success depends on three factors: time, cost, and quality (Elzomor & Parrish, 2016). These factors can be the pillars to achieve sustainability goals (Elzomor & Parrish, 2016). The goal of sustainable construction can be achieved by considering the aspects of sustainability. In line with the objectives of sustainable development, sustainable construction can be examined from three perspectives: sociocultural, economic, and environmental (Araújo et al., 2013; R. C. Hill et al., 1994; Moradi & Kahkonen, 2022; Rajabi et al., 2022; Said et al., 2010; Salah et al., 2023). However, in some references, it is divided into four aspects, adding technological sustainability (R. C. Hill & Bowen, 1997; Thomas et al., 2023; Zabihi et al., 2012), which shows the importance of technological aspects in sustainable construction. Construction activities are largely concerned with improving the quality of human life, so with a responsible approach to the ecosystem' carrying capacity, the goal of "sustainability" can be achieved from an economic and environmental perspective (R. C. Hill et al., 1994). These aspects of sustainability are assessed through several indicators. These aspects of sustainability are assessed using several indicators. Table 1 and Fig. 3 summarize the indicators used in previous studies to assess sustainable construction.

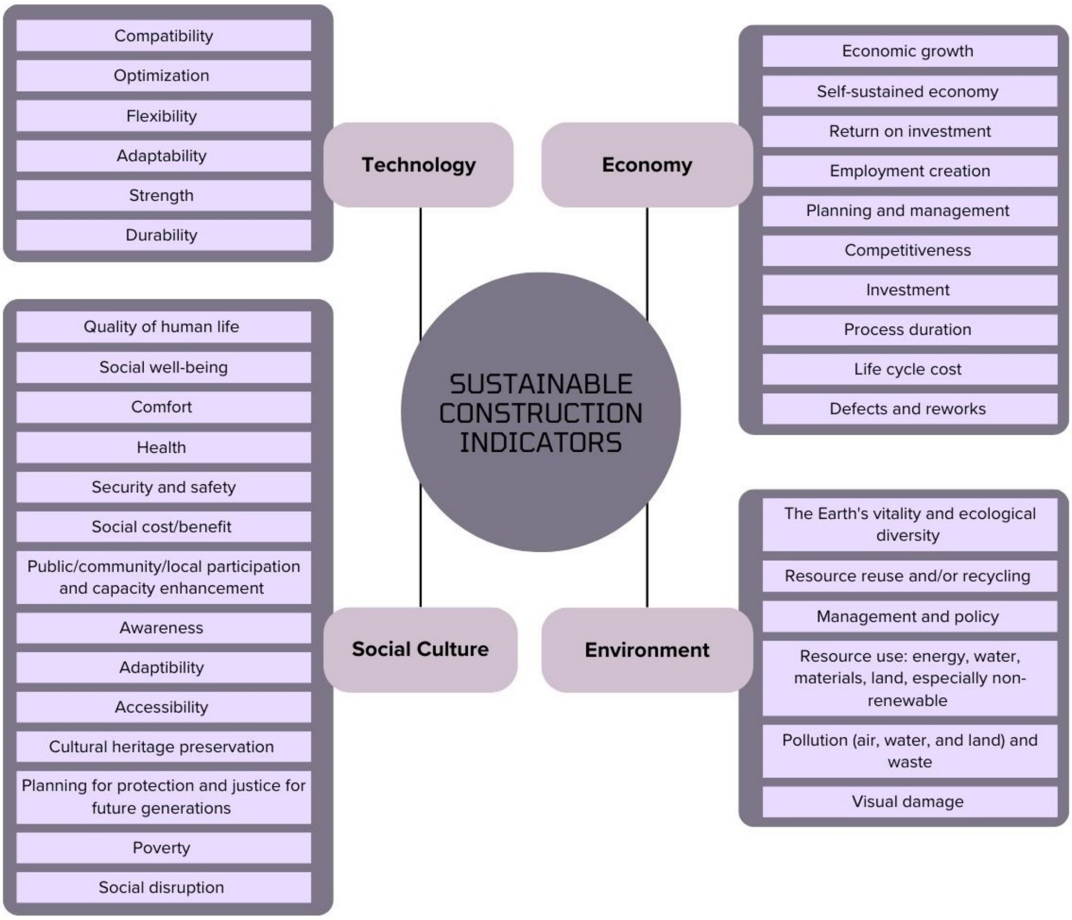

Fig. 3. Sustainability Indicators in Construction
Source: Authors (2024)

Table 2. Indicators of Sustainability Achievement in the Construction Sector

Aspect	Indicators	Reference Sources
Social Culture	Quality of human life	(R. C. Hill et al., 1994; R. C. Hill & Bowen, 1997; Said et al., 2010)
	Social well-being	(Moradi & Kahkonen, 2022; Salah et al., 2023)
	Comfort	(Araújo et al., 2013; Salah et al., 2023; Thomas et al., 2023)
	Health	(Araújo et al., 2013; R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022)
	Security and safety	(R. C. Hill & Bowen, 1997; Rajabi et al., 2022; Thomas et al., 2023; Zuo et al., 2014)
	Social cost/benefit	(R. C. Hill et al., 1994; R. C. Hill & Bowen, 1997; Thomas et al., 2023)
	Public/community/local participation and capacity enhancement	(R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022; Rajabi et al., 2022; Thomas et al., 2023; Zabihi et al., 2012)
	Awareness	(Thomas et al., 2023)
	Adaptability	(Thomas et al., 2023)
	Accessibility	(Moradi & Kahkonen, 2022)
	Cultural heritage preservation	(Moradi & Kahkonen, 2022)
	Planning for protection and justice for future generations	(R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022; Said et al., 2010)
	Poverty	(R. C. Hill & Bowen, 1997)
	Social disruption	(R. C. Hill et al., 1994)
Economy	Economic growth	(Said et al., 2010)
	Self-sustained economy	(Said et al., 2010)
	Return on investment	(Salah et al., 2023)
	Employment creation	(Hill & Bowen, 1997)
	Planning and management	(Moradi & Kahkonen, 2022; Zabihi et al., 2012)
	Competitiveness	(Hill & Bowen, 1997)
	Investment	(R. C. Hill & Bowen, 1997)
	Process duration	(Thomas et al., 2023)
	Life cycle cost	(Araújo et al., 2013; R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022; Salah et al., 2023; Thomas et al., 2023)
	Defects and reworks	(Moradi & Kahkonen, 2022)
Environment	The Earth's vitality and ecological diversity	(R. C. Hill et al., 1994; R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022; Rajabi et al., 2022; Zabihi et al., 2012)
	Resource reuse and/or recycling	(R. C. Hill & Bowen, 1997)
	Management and policy	(Salah et al., 2023)
	Resource use: energy, water, materials, land, especially non-renewable	(Araújo et al., 2013; R. C. Hill et al., 1994; R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022; Rajabi et al., 2022; Said et al., 2010; Salah et al., 2023; Thomas et al., 2023; Zabihi et al., 2012)
	Pollution (air, water, and land) and waste	(Araújo et al., 2013; R. C. Hill et al., 1994; R. C. Hill & Bowen, 1997; Moradi & Kahkonen, 2022; Rajabi et al., 2022; Said et al., 2010; Salah et al., 2023; Thomas et al., 2023)
	Visual damage	(R. C. Hill et al., 1994; R. C. Hill & Bowen, 1997)
Technology	Compatibility	(R. C. Hill et al., 1994)
	Optimization	(Zabihi et al., 2012)
	Flexibility	(Zabihi et al., 2012)
	Adaptability	(Moradi & Kahkonen, 2022)46]
	Strength	(R. C. Hill & Bowen, 1997; Thomas et al., 2023)
	Durability	(R. C. Hill & Bowen, 1997; Thomas et al., 2023)

Source: Authors (2024)

C. Sustainable Construction Materials

Building materials are one of the main inputs in construction activities (Pheng & Hou, 2019) and are the main component determining the total construction cost (Ive & Gruneberg, 2000). This component is required at each stage of construction, as shown in Fig. 4. The type of building material directly influences the technique used for construction which directly influences emissions at the construction stage, such as environmental impacts due to the transportation, preservation, and processing of materials (Sandanayake, 2022). Using sustainable building materials has become a major focus in minimizing the construction industry's environmental impact and is an effective step in achieving sustainable construction goals (Baglou et al., 2017; Ding, 2014). The selection of sustainable materials represents a significant challenge, given the numerous variables and potential uncertainties involved in the analysis (Song & Zhang, 2018).

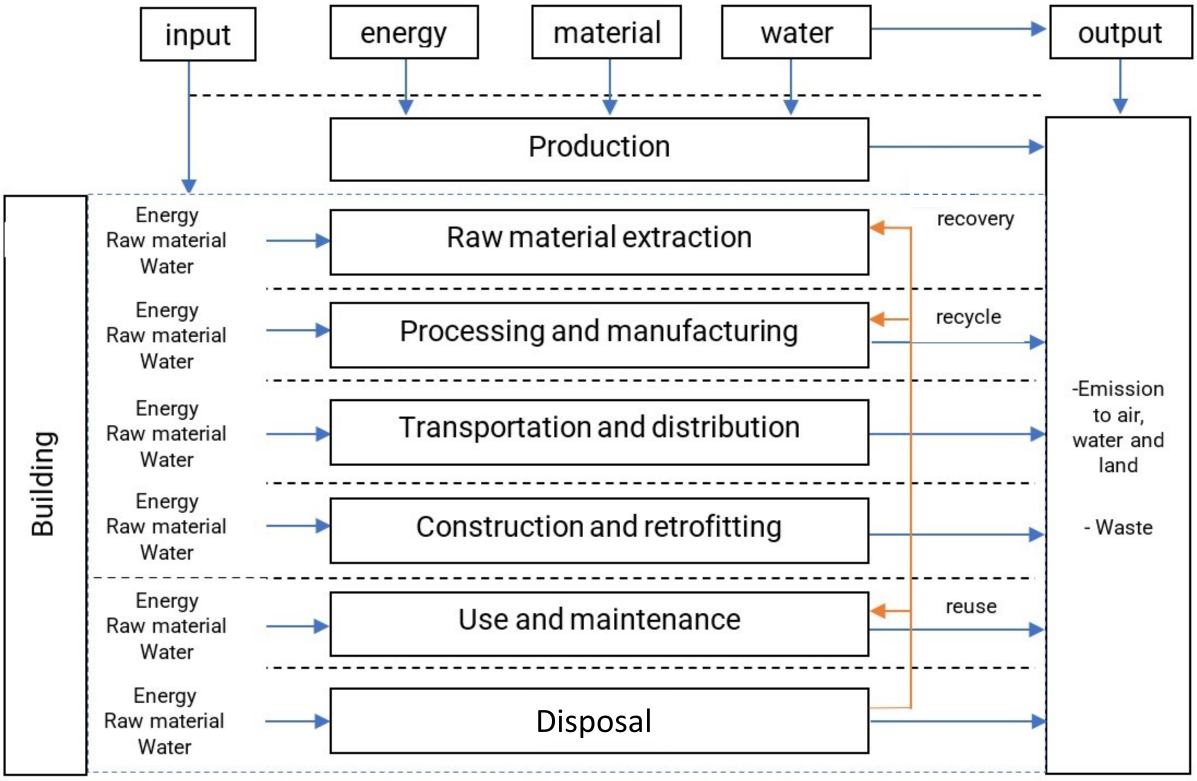

Fig. 4. Use of Materials in the Construction Process
Source: modification from Ding (2014); Huang et al. (2020)

Sustainable building materials are sustainable throughout their life cycle, require less energy use in the production, and do not emit pollutants or other emissions that impact human health and comfort (Ding, 2013). Resource and energy efficiency and pollution prevention are criteria relating to sustainable construction materials (Barbhuiya & Das, 2023; Ding, 2014). Researchers use various indicators to assess the sustainability of a material. The indicator categories used for sustainable materials are similar to those used for sustainable construction. Indicators for assessing the sustainability of materials used in previous studies include sociocultural, economic, and environmental aspects (Ahmad & Alwafi, 2022; Al-Atesh et al., 2020; Baglou et al., 2017; Danso, 2018) and mechanical (Takano et al., 2014).

D. Wood as a Sustainable Construction Material

Previous studies have highlighted that wood has renewable and low-impact characteristics as a construction material compared to other alternatives (Barbhuiya & Das, 2023). Wood can be important in achieving sustainable construction goals as a renewable material. Three stages in the life of a wood product are important in evaluating its sustainability: raw material procurement, material manufacture, and end-of-life (Goldhahn et al., 2021). Fig. 5 shows a schematic of the wood life cycle from tree regeneration to wood use.

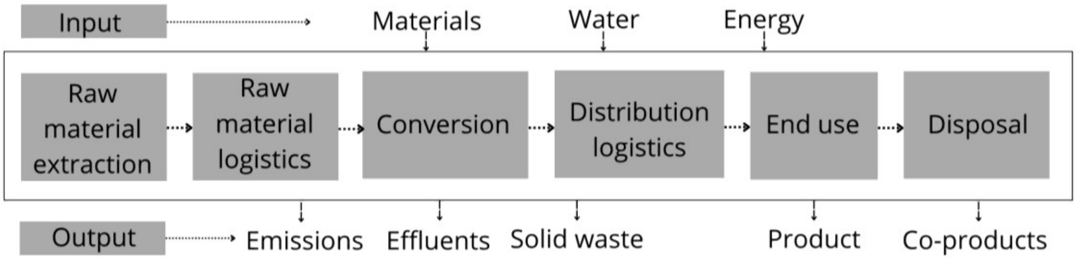

Fig. 5. Scheme of the Wood Utilization Cycle
Source: Barbhuiya and Das (2023)

To assess the use of wood in support of sustainable construction goals, the literature discussing wood materials in each of the sustainable construction indicators summarized previously was reviewed. Table 2 presents the literature discussing wood materials in each indicators.

Table 2. Literature Review on the Use of Wood Materials Based on Sustainable Construction Indicators

Sustainable Construction Aspect	Reference Sources	Sustainable construction indicators discussed
Social Culture	(Kotradyova et al., 2019)	Quality of human life
	(Watchman et al., 2017)	Comfort
	(Alapieti et al., 2020)	Health
	(Franzini et al., 2018)	Social benefit
Economy	(Araujo, 2023)	Economic growth
	(Hynynen, 2016)	Employment creation
	(Arumägi & Kalamees, 2020; Bhochhibhoya et al., 2017; Švajlenka & Kozlovská, 2018)	Life cycle cost
	(Pasternack et al., 2022; Riala, 2013)	Competitiveness
	(Švajlenka & Pošiváková, 2023)	Process duration
Environment	(Churkina et al., 2020; Goldhahn et al., 2021; Hepburn et al., 2019; Ramage et al., 2017)	The Earth's vitality and ecological diversity
	(Ramage et al., 2017)	Resource reuse and/or recycling
	(C. Hill et al., 2022)	Resource use: energy, water, materials, land, especially non-renewable
	(Akpan et al., 2021)	Pollution (air, water and land) and waste
Technology	(Green, 2001; Jakob et al., 2022)	Optimization
	(Irle, 2019)	Flexibility
	(Green, 2001; Jakob et al., 2022)	Strength
	(Ramage et al., 2017; Unterrainer, 2018)	Durability

Source: Authors (2024)

Based on the results of the literature review on wood as a construction material, several things can be used as a framework for using wood to support sustainable building goals, as shown in Fig. 6. The discussion of each of these aspects is as follows:

- Technology aspects: The properties of wood materials are strongly influenced by their growth and the environment in which they will be in use (Jakob et al., 2022). Wood is a material that offers strength and flexibility, but it needs to be used according to how and where it is used

(Green, 2001; Jakob et al., 2022), including the type, direction, and duration of loading; the environmental conditions of moisture content and temperature; and the presence or absence of defects (Green, 2001) to get optimal performance. Wood materials for construction have the disadvantage of durability. Design considerations for exposure of timber components to moisture and direct sunlight must also be taken into account to improve their durability (Ramage et al., 2017). Physical and chemical treatments can be used to improve wood products' durability to support sustainable construction goals (Ramage et al., 2017). Still, physical and chemical treatments do not impact on the environment (Goldhahn et al., 2021). Technology, such as mass timber technology and cross-laminated timber (CLT), is also being used to enhance its capabilities (Pasternack et al., 2022). CLT is a rigid panel product consisting of an appropriate number of layers (usually an odd number: 3, 5, or 7). Each layer consists of boards placed side by side, and adjacent layers are usually glued at 90° to each other (Jeleč et al., 2018). The CLT technology can increase the capacity of wood materials even for multi-story buildings. Constructing multi-story buildings using timber materials will expand the range of timber building applications.

- Environmental aspects: From an environmental perspective, wood-based materials have been studied and found to have a low impact on energy use and emissions compared to other materials (C. Hill et al., 2022). A comparison of the embodied energy and carbon content of timber structures built off-site with those built using conventional methods shows that the impact of masonry structures is greater (C. Hill et al., 2022). To support sustainable construction, the use of wood materials should be considered based on their species and reproductive potential, taking into account a service life that corresponds (at least) to the timber rotation period, thus allowing for "sustainable harvesting" (Ramage et al., 2017). The wood used can not come from massive deforestation (Goldhahn et al., 2021). The rotation period for harvesting wood materials is essential because wood must have a continuous supply. Forest management, which ensures the availability of wood-based materials and the sustainability of forests, is an important part of this. Consideration in the provision of production forests is also a measure to maintain the continuous availability of wood materials. In the manufacturing phase, modifications are made to ensure that products and processes have little or no potential to pollute or cause environmental risks while remaining economically and technologically feasible (Goldhahn et al., 2021). The lifespan of a building is also an important consideration, as the longer a building's lifespan, the more it supports decarbonization efforts (Churkina et al., 2020; Hepburn et al., 2019). In the end phase, the use of wood materials suggests following the principle of cascading use, including wood-based products, reuse, recycling, bioenergy, and disposal (Ramage et al., 2017)
- Economic aspects: Wood construction is a promising segment for economic growth through the development of the bio-economy (Araujo, 2023), which will indirectly impact on job creation (Hynynen, 2016). Increasing competitiveness regarding wood prices and construction skills is necessary as wood materials are currently only considered competitive in small-scale construction (Riala, 2013). Mass timber and cross-laminated timber (CLT) technology is an alternative that can increase the ability to construct taller timber buildings (Pasternack et al., 2022). In addition, the use of prefabricated wooden structures is expected to reduce construction costs and make prices more affordable (Arumägi & Kalamees, 2020). One of the advantages of timber construction is efficiency in construction time (Švajlenka & Pošiváková, 2023), which can increase its economic value. However, this needs to be supported by using locally sourced wood materials to make it more cost-effective and environmentally friendly (Švajlenka & Kozlovská, 2018). Local materials are more environmentally friendly than others due to the lower impact of material production and transport requirements, affecting construction costs (Bhochhibhoya et al., 2017).
- Socio-cultural aspects: The use of wood materials has been studied to have a positive influence on human well-being, especially during building operations. Wood materials can have positive benefits on the human nervous system through attractive aesthetics (color, texture, and structure), high contact comfort, pleasant smell, ability to regulate air humidity and volatile organic compound emissions (VOC-emissions), and indoor acoustics (Kotradyova et al., 2019). Humans feel satisfied with wood in terms of lighting, noise, and temperature (Watchman et al., 2017). Additionally, wood has been demonstrated to exert a beneficial or neutral influence on indoor air quality. This encompasses the capacity to regulate fluctuations in indoor humidity,

induce positive emotional states in occupants, and impede the growth of certain bacteria (Alapieti et al., 2020). Negative impacts are limited to VOC released from the wood (Alapieti et al., 2020). From another social aspect, using wood materials can create additional demand for forest products, thereby increasing the productivity of forest sector actors, which encourages the creation of social benefits from using wood materials (Franzini et al., 2018).

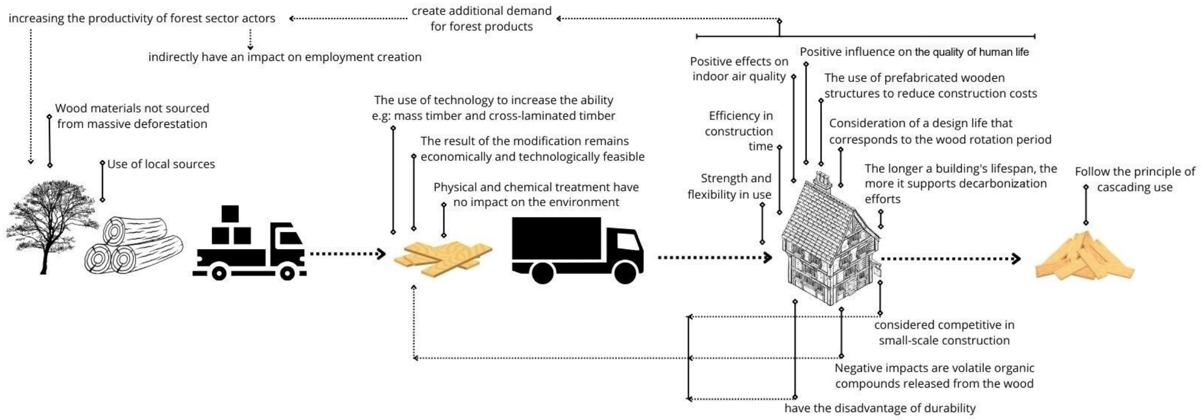

Fig. 6. Schematic Principle of Using Wood Materials for Sustainable Construction
Source: Authors (2024)

III. Conclusion

The literature review conducted in this paper highlights several important points about the role of wood in supporting sustainable construction. Every aspect of sustainable construction, including socio-cultural, economic, environmental, and technological, can be seen in the role of wood materials in supporting sustainable construction goals. Several disadvantages of using wood materials are also discussed in this paper, and several approaches to overcome them have also been discussed in the available literature. In the available literature, environmental aspects are very much emphasized in the discussion. According to R. C. Hill et al. (1994), construction activities are largely concerned with improving the quality of human life so that the goal of "sustainability" can be achieved from both economic and environmental perspectives through an environmentally responsible approach. The importance of technology in overcoming various weaknesses of wood materials has become a concern in the existing literature and an opportunity for future research to improve the performance of wood materials. This paper still has limitations because the review focuses on indicators found in the existing literature. Some aspects may only be covered if they are included in the selected indicators. The indicators used are also still broad, so further research is needed on the sustainability aspects of wood materials. For example, the selection of local materials to be considered for sustainable constructionrequires further research as this review is not site-specific.

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