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Sustainable design of tall buildings

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Professional paper

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Tall buildings cause more environmental difficulties in their life cycles than low-rise buildings. In order to decrease these difficulties, the carrier system design and sustainable design should be considered together in the design of tall buildings. The application of sustainable design criteria on 13 buildings certificated according to LEED (Leadership in Energy and Environmental Design) is considered in the paper. The application of these criteria on the studied tall buildings is evaluated in the context of the evaluation method proposed in the paper.

Key words:
sustainable design, tall buildings, LEED, green building

Stručni rad

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Održivo projektiranje visokih građevina

Visoke građevine uzrokuju više ekoloških poteškoća u toku svog vijeka trajanja nego što je to slučaj kod niskih građevina. Da bi se umanjili takovi utjecaji, projektiranje nosivog sustava i održivo projektiranje treba se razmatrati zajednički kod projektiranja visokih građevina. U radu se razmatra primjena kriterija održivog projektiranja na 13 građevina certificiranih prema LEED-u (Leadership in Energy and Environmental Design). Primjena tih kriterija ocjenjuje se na promatranim visokim građevinama u kontekstu metode ocjenjivanja koja se predlaže u radu.

Ključne riječi:
održivo projektiranje, visoke građevine, LEED, zelena gradnja

Fachbericht

Arzuhan Burcu Gültekin, Seda Yavaşbatmaz

Nachhaltige Planung von Hochhäusern

Hochhäuser haben im Laufe ihrer Lebensdauer weitreichendere Einflüsse auf die Umwelt als niedrige Gebäude. Um diese Einflüsse zu vermindern, sollte die Berechnung des Tragwerkes und die nachhaltige Planung im Entwurf von Hochhäusern als eine Einheit betrachtet werden. In der vorliegenden Arbeit ist der Einsatz nachhaltiger Planungskriterien an 13 nach LEED (Leadership in Energy and Environmental Design) zertifizierten Hochhäusern untersucht worden. Die Anwendung dieser Kriterien am Beispiel der betrachteten Gebäude wird durch eine in der vorliegenden Arbeit vorgeschlagene Bewertungsmethode beurteilt.

Schlüsselwörter:
nachhaltige Planung, Hochhäuser, LEED, grünes Bauen

1. Introduction

17 % of water sources, 25 % of forestry products and 40 % of energy sources are consumed by the building sector [1, 2]. The manufacturing, construction, operation, maintenance, repair and demolition activities of the buildings affect natural environment and therefore buildings may harm the environment throughout their life cycles [3].

Today, the number of tall buildings has increased in order to use urban areas economically without harming the environment [4]. It can be stated that costs of energy and natural resources used by tall buildings throughout their life cycle are higher compared to other structures because they have more floors. Therefore, tall buildings are perceived as the buildings that use energy and natural resources inefficiently [5]. As a solution to this problem, a sustainable design concept has emerged for tall buildings.

The aim of sustainable design for tall buildings is to create designs that reduce the use of natural resources, use local resources economically, do not disrupt ecological balance, minimize the harmful effects of buildings on the environment, and provide necessary conditions for human comfort and health [6]. In this context, sustainable design for tall buildings can be examined under three headings: ecological, economical and sociocultural.

Effective use of fields, water, energy and materials should be taken into consideration during the design process in the scope of ecological sustainable design. Economic constraints should be determined by using the sources effectively and performing cost analyses within the context of sustainable economical design. On the other hand, indoor life quality should be enhanced and innovative applications should be included in the context of sociocultural sustainable design.

In this article, the intention is to increase awareness of the need for sustainable design of tall buildings that increase in number with technological developments, and to sensitize researchers and designers to the issue of sustainable tall buildings. The aim of this article in the scope of this intention is to present a guiding framework to all stakeholders involved in the building sector so as to encourage application and dissemination of the sustainable design criteria for tall buildings at the local and global level.

2. Tall building design

The density of population has increased and the need to develop urban centers is increasingly felt throughout the world. In line with this need, numbers of floors of the buildings increased and the notion of "tall building" emerged [7].

The Council on Tall Buildings and Urban Habitat (CTBUH) of the USA defines tall buildings in three ways: "architectural height excluding technical equipment such as antennas and flagpoles; height from the ground to the highest flooring; and height from the ground to the highest point of the structure including technical equipment such as antennas and flagpoles [8]". On the other hand, when the issue is considered in the framework of legal regulations, the Metropolitan Municipality of Ankara-Turkey defines structures with building heights of 21.5 meters or above, and with structure heights of 30.5 meters or above, as tall buildings in the Building Bylaws [9].

Tall building design has been rapidly improving due to reasons such as technological developments, international competition, and commercial benefits. Tall buildings should be designed by handling both carrier system design such as carrier system materials and carrier system types, and architectural design such as local conditions, ground conditions, earthquake situation, fire endurance, equipment systems, and geometrical type.

Ecological, economical and sociocultural components such as increasing the use of renewable energy sources, minimizing inputs during the manufacturing process, minimizing the use of raw materials and energy consumption, and increasing user comfort, should also be considered in the design of tall buildings. In this context, carrier system design and sustainable design concepts come into prominence for tall buildings.

Sustainable design is being implemented worldwide for both low-rise buildings and tall buildings. However the international community is divided as to sustainability credentials of tall buildings. There are those who defend the position that densely populated city centers with tall buildings are inherently sustainable, while others believe that the high amount of energy embodied in tall buildings is the indicator of unsustainability. Regardless of these two opinions, this article attempts to give educational information on the carrier system design and sustainable design of tall buildings.

2.1. Carrier system design of tall buildings

A carrier system is a structure composed of load carrying elements that transfer forces and loads exerted on the building in order to provide the envisaged static balance [10]. The aim of the carrier system is to create an effective and economical system that will meet appropriate functional and aesthetical requirements. The carrier system design for tall buildings is more important when compared to the low-rise and medium-size buildings, because vertical and horizontal loads increase with the height of the building [4].

Since the use of materials increases considerably with the height, attempts to minimize the use of materials in carrier systems is of great importance in terms of sustainability. The steel, concrete or composite materials (concrete + steel) are used in tall buildings as structural materials. Various carrier systems have been developed for tall buildings which

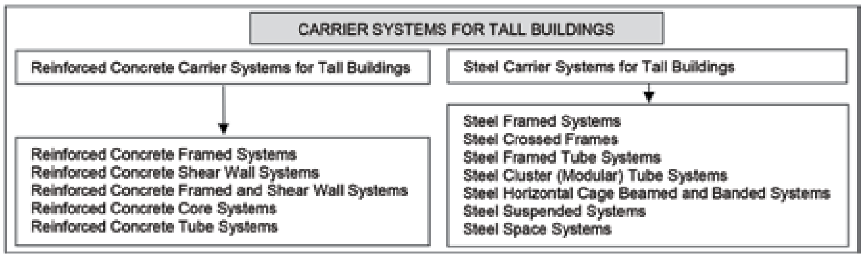


Figure 1. Classification of carrier systems for tall buildings [6]

involve joint use of concrete and steel, as shown in Figure 1. The design of tall buildings is directly affected by carrier system materials and types. The creation of effective usage areas, and minimization of construction costs, are possible with the selection of an appropriate carrier system. In this context, the selection of carrier system is important for sustainable design.

At the first sight, it may be thought that the design of carrier system for tall buildings is not related to sustainability. However, the carrier system of tall buildings requires a large amount of structural material. At the same time, the energy embodied in the carrier system material for tall buildings is higher than that of low-rise buildings. Accordingly, selection of the carrier system material is essential in terms of sustainability and economical design. As buildings get taller, the carrier frame becomes heavier. For instance, core takes an important role in assuming horizontal loads in the carrier system design. An appropriate core design improves the usage of floors and takes maximum advantage of the sun. In this case, it can be stated that carrier system design for tall buildings is essential in terms of sustainable design [11].

2.2. Sustainable design of tall buildings

The sustainable design of tall buildings is the design that makes the building operational at minimum cost by minimizing energy consumption and use of resources [12]. The cost of energy and natural resources used by tall buildings at the stages of construction, use, and demolition, is higher when compared to low-rise buildings [13]. The sustainable design of tall buildings can be regarded as a solution to this problem. On an international scale, tall buildings are evaluated in the framework of international certification systems which have various sustainability criteria classifications. These systems contribute to minimization of environmental impacts of buildings, and are highly useful to the designers.

LEED (Leadership in Energy and Environmental Design) is one of the internationally recognized certification systems developed by the U.S. Green Building Council. LEED projects have been successfully established in 135 countries. International projects, those outside the U.S., make up more than 50 % of the total LEED registered square footage. LEED provides building owners and operators with a framework for identifying and implementing practical and measurable sustainable building design, construction, operation, and maintenance solutions, while providing healthy indoor spaces for building occupants. LEED is a voluntary, consensus-based, market-driven program that provides third-party verification of sustainable buildings. From individual buildings and homes, to entire neighborhoods and communities, LEED is transforming the way built environments are designed, constructed, and operated. Comprehensive and flexible, LEED addresses the entire lifecycle of a building. LEED certificated buildings are designed to lower operating costs and increase asset value, reduce waste sent to landfills, conserve energy and water, be healthier and safer for occupants, reduce harmful greenhouse gas emissions, and qualify for tax rebates, zoning allowances and other incentives in cities. The rating of LEED system is based on "platinum, gold, silver and certificated" levels. Platinum is considered as the highest level and the other levels follow as shown above [14-16].

Certification systems are not widely-used in Turkey. 4 % of all buildings certificated in Turkey are residences, 6 % are hotels, 2 % are laboratories, 20 % are malls, 12 % are factories, and 50 % are offices [17]. Most of these buildings have LEED certificates: 2 have LEED Platinum, 25 LEED Gold, and 9 LEED Silver, two of which are tall buildings. At the same time, there are approximately 132 building projects registered for LEED certification, 14 of which are tall buildings.

Turkish Green Building Council developed a beta version of the Turkish sustainable building certification system for homes in December 2012 according to local conditions and criteria. It consists of 8 main categories. integrated green project management, land use, water use, energy use, health and wellbeing, material and resource use, home living, and operation and maintenance. The rating of the system is based on a four leafed clover. One leafed clover is considered as certification–pass, two leafed as good, three leafed as very good, and four leafed as excellent [18, 19].

In this article, sustainable design criteria and related methods to provide these criteria are classified in a conceptual framework as presented in Figure 2. For this classification, both the sustainability criteria in different scientific studies [6, 20 - 22] and the LEED evaluation criteria [23] are considered.

2.2.1. Ecological sustainable design of tall buildings

Sustainable design for tall buildings includes construction materials that are sensitive to the environment, reusable and renewable, that minimize energy consumption, use renewable and local resources thus reducing the use of non-renewable natural resources, create healthy indoor areas, use solar power, natural ventilation and natural illumination, and do not require frequent maintenance and repair [24].

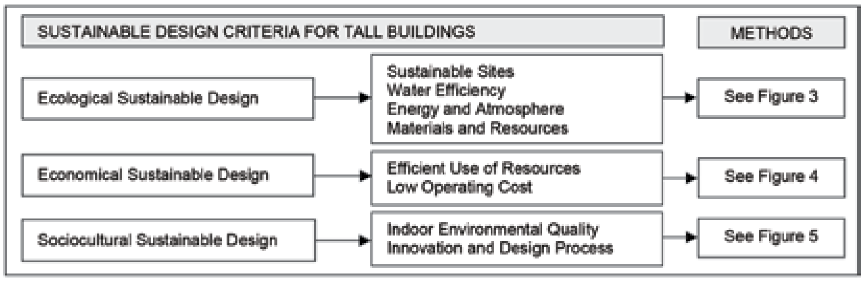


Figure 2. Sustainable design criteria for tall buildings

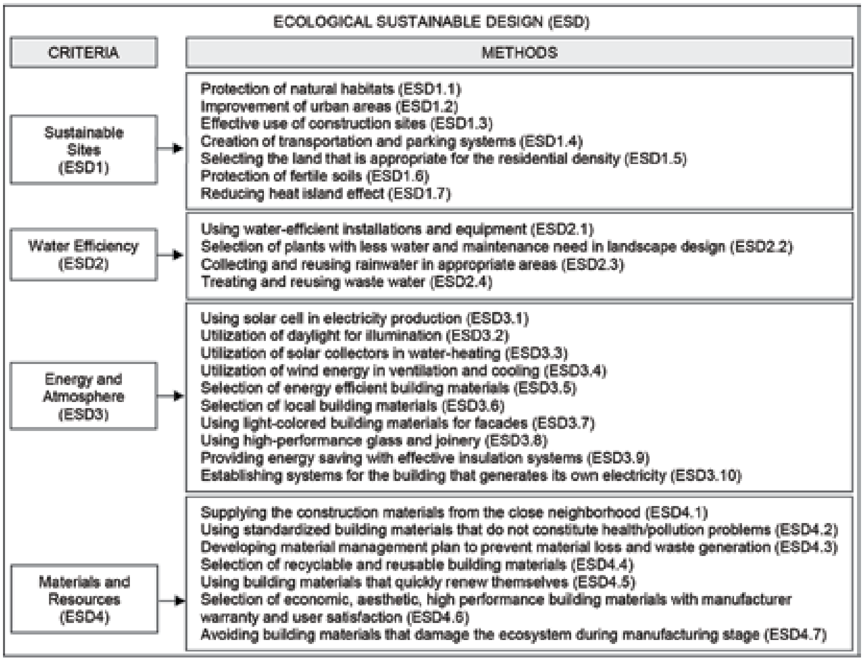


Figure 3. Criteria and methods for ecological sustainable design of tall buildings

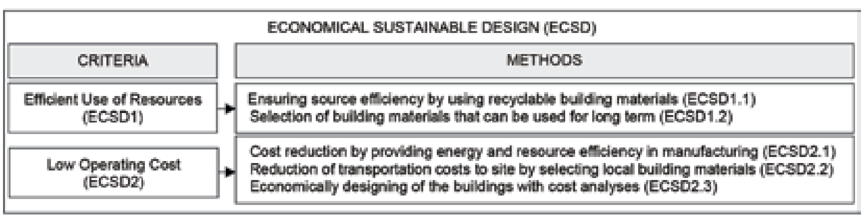


Figure 4. Criteria and methods for economical sustainable design of tall buildings

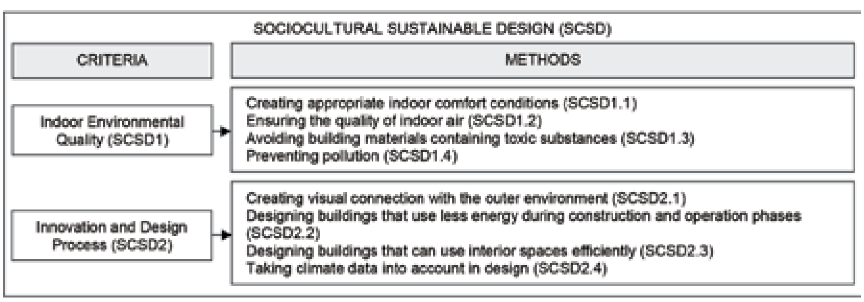


Figure 5. Criteria and methods for sociocultural sustainable design of tall buildings

The emphasis for tall buildings should be placed on effective usage of construction site, water, natural resources, materials and energy in the context of ecological sustainable design [6]. In this context, ecological sustainable design criteria can be classified as "sustainable sites", "water efficiency", "energy and atmosphere" and "materials and resources". The criteria and methods for ecological sustainable design of tall buildings are given in Figure 3.

2.2.2. Economical sustainable design of tall buildings

Economical sustainable design consists of designs that are created within the framework of low cost, high efficiency, healthy development and improvement [25]. Decisions that do not take the sustainability criteria into consideration at the design stage result in high costs throughout the useful life of both low-rise and tall buildings. When considering a sustainable low-rise or tall building, cost analyses covering the construction, use, maintenance, repair, operation, and demolition phases, should be carried out at the design stage. Economical design is more significant in case of tall buildings compared to low-rise buildings, because tall buildings consume more material, energy and water. Economy of a tall building depends on construction materials, energy, labor and operating costs used in all phases beginning from the design stage until demolition of the building [4]. In this context, economical sustainable design criteria can be classified as "efficient use of resources" and "low operating cost". The criteria and methods for economical sustainable design of tall buildings are given in Figure 4.

2.2.3. Sociocultural sustainable design of tall buildings

Sociocultural sustainability can be defined as the implementation of methods for protecting human health and enhancing comfort conditions. Tall buildings should be taken into consideration along with the surrounding environment, and innovative applications should be included to create a high quality indoor setting by providing healthy and comfortable living space, and by keeping the users in touch with the outside environment [26]. In this context, sociocultural sustainable design criteria can be classified as "indoor environmental quality" and "innovation and design process". The criteria and methods for sociocultural sustainable design of tall buildings are given in Figure 5.

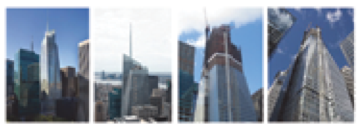
TALL BUILDINGS		SUSTAINABLE DESIGN CRITERIA
Bank of America Tower New York - USA [27, 28]		ESD: Green roof method is applied on the tower to decrease the urban heat island effect. Wastewater is stored and used in appropriate fields. All of the building materials used in the construction of the tower was supplied from a distance of maximum 800 km. The steels used in the carrier system were obtained by recycling scrap metals. A significant part of the electric energy of the tower is generated by the 4600 kW power cogeneration system.
	Height: 365.8 m *Number of Floors:* 58 *Function:* Office *Certificate:* LEED Platinum *Start-End Date:* 2004-2009 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core + Steel frame	ECSD: Energy and source efficiency were provided by selecting recyclable materials that can be used for long term for the construction of the tower.
	Architectural Design: Cook + Fox Architects - Adamson Associates Architects Structural Design: Severud Associates Consulting Engineers	SCSD: Fresh air entrance into the building is provided by means of air filtration system. Sustainable building materials that do not contain toxic materials were used in the indoor spaces.
The Visionaire Building New York - USA [29, 30]		ESD: Green roof contributes to reducing the effect of heat island. Rainwater collected on the roof is used for irrigation of green areas. Electricity is generated by the solar cells that are mounted on the external wall of the building from the solar power. The materials used in the construction of the building were supplied from a distance of 800 km and from reachable resources. Self-renewing building materials such as bamboo were used for the indoor spaces.
	*Height:*109.73 m *Number of Floors:* 35 *Function:* Residence *Certificate:* LEED Platinum *Start-End Date:* 2006-2008 *Carrier system material:* Concrete *Carrier system:* Reinforced concrete column + Beamless floor	ECSD: Energy and source efficiency were provided by selecting recyclable materials that can be used for long term for the construction of Visionaire Building. Supplying the materials used in the construction of the building from the surrounding neighborhood contributed to the economical sustainability design.
	Architectural Design: Cesar Pelli & SLCE *Structural Design:* DeSimone Consulting Engineers	SCSD: Building materials that do not contain toxic materials were used in the construction of the building. Fresh air entrance into the building is provided by means of air filtration system. Urban water is treated with central filtration system and then provided for the users.
Taipei Financial Center Taipei – Taiwan [4, 31, 32]		ESD: Water need of the tower is reduced by a rate of 20-30% by using recyclable water. Plants that can be irrigated by rainwater were selected in landscape design. Rain water is collected and used to irrigate plants and in toilets. 16 kWh energy can be generated by using the solar cells. Heat gain and loss decreased by 50% percent by double glazing facade system application.
	Height: 509.2 m *Number of Floors:*101 *Function:* Office *Certificate:* LEED Platinum *Start-End Date:* 1999-2004 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core+Steel crossed beam	ECSD: The tower can meet some part of its energy need by means of the solar cells. Energy costs were reduced by decreasing the energy consumption by 30%. Economical sustainable design is supported by keeping the source consumption under control as well as energy efficiency.
	Architectural Design: C.Y. Lee & Partners *Structural Design:* Thornton Tomasetti	SCSD: In order to limit the horizontal oscillations and vibrations to ensure user comfort, weighs 650 tons of metal pendulums was placed on floor 88 as mass muffle system.

Figure 6. The features of tall buildings examined in the context of sustainable design

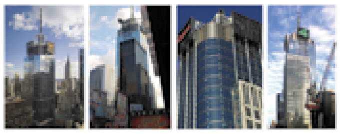
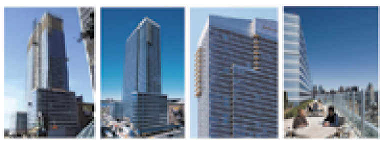
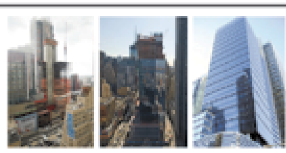
TALL BUILDINGS		SUSTAINABLE DESIGN CRITERIA
Condé Nast Building New York - USA [4, 33]		ESD: Low flow taps were selected for bathrooms. Solar cells were installed on upper floors to benefit from renewable energy. Glasses with high light transmission value were used for lower floors and high performance glasses were used for upper floors to decrease the effect of sunlight. Fuel cells installed on the roof generates electric energy.
	Height: 338 m *Number of Floors:* 48 *Function:* Office *Certificate:* LEED Gold *Start-End Date:* 1996-1999 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core + Steel frame	ECSD: Source efficiency is provided by using recyclable materials. Energy costs are reduced as the building can meet some part of its energy need. Saving was achieved in the costs of transportation to the site by supplying the building materials used in the construction of the building from the surrounding neighbourhood.
	Architectural Design: Fox & Fowle Architects *Structural Design:* WSP Contor Seinuk	SCSD: Air quality is controlled by the air conditioner stations on every floor of the building. Building materials that do not contain toxic materials were used in the indoor spaces. Detached chimneys that enable direct ventilation from smoking rooms and photocopy rooms were constructed.
The Helena Building New York – USA [34-36]		ESD: Green roof contributes to reducing the effect of heat island. Rainwater is collected and used for irrigation of green areas. Electric is generated by the solar cells. 20% of the materials used in the construction of the building were supplied from a distance of 800 km and thus use of local materials was supported. Harmful effects of sunlight are reduced in the indoor areas by means of the high performance façade elements.
	Height: 122.07m *Number of Floors:* 39 *Function:* Residence *Certificate:* LEED Gold *Start-End Date:* 2003-2005 *Carrier system material:* Concrete *Carrier system:* Reinforced concrete column + Beamless floor	ECSD: Energy and source efficiency were provided by selecting recyclable materials that can be used for long term for the construction of the building. Obtaining the energy needs of the building from renewable energy sources minimizes energy consumption.
	Architectural Design: Fox & Fowle Architects with Harman Jablin *Structural Design:* Severud Associates	SCSD: Harmful effects of ultraviolet lights on furniture are reduced by means of high performance double glazing application. Fresh air entrance to the indoor areas and visual connection with the outer environment are provided by the openable windows.
11 Times Square Building New York – USA [37-39]		ESD: The methods such as rainwater collection and recycling system, installation system that provides water efficiency, air filtration system, high efficiency façade components on the external façade and standardized construction materials were applied. Sun-shading used on the external wall prevents the harmful effects of sunlight and contributes to reducing the energy consumption of the building.
	Height: 183 m *Number of Floors:* 40 *Function:* Office *Certificate:* LEED Gold *Start-End Date:* 2007-2010 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core + Steel frame	ECSD: High performance façade components on the external wall of the building optimize heat gain and loss and contribute to reducing the energy consumption of the building.
	Architectural Design: Fox & Fowle Architects *Structural Design:* Thornton Tomasetti	SCSD: Construction materials that do not affect human health negatively were used within the indoor areas. One of the most important features of 11 Times Square Building for tenants is the incorporation of advanced air filtration and ventilation technology that optimizes indoor air quality. Life quality is increased by providing fresh air entrance into the indoor areas. Reflection is controlled by means of the sun-shading placed on the external wall.

Figure 6. (Cont.) The features of tall buildings examined in the context of sustainable design

3. Evaluation of tall buildings in the context of sustainable design

In this section, the application of sustainable design criteria, as specified in tables in Chapter 2.2 on LEED certificated tall buildings, is studied. Sustainable design criteria of tall buildings are evaluated in terms of ecological, economical and sociocultural aspects, based on study results.

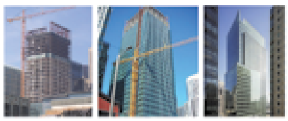
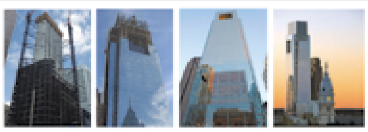
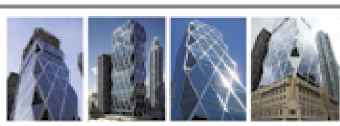
TALL BUILDINGS		SUSTAINABLE DESIGN CRITERIA
7 World Trade Centre New York – USA [40, 41]		ESD: Water consumption is reduced by 30% by means of the water system that uses the water effectively. Wastewater is stored on the roof and used in appropriate fields. Electric energy of the building is regenerated by the microturbines. Approximately 30% of the steel material used in the construction of the building is recyclable.
	Height: 226 m *Number of Floors:* 52 *Function:* Office *Certificate:* LEED Gold *Start-End Date:* 2002-2006 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core + Steel frame	ECSD: Source efficiency is provided by using recyclable materials for the construction of the building. Transportation cost to the site was decreased by selecting the local construction materials.
	Architectural Design: David Childs (SOM) *Structural Design:* WSP Cantor Seinuk	SCSD: Sun-shading installed on the external wall takes the harmful effects of sunlight under control and appropriate comfort conditions are created within indoors. Users are provided with the opportunity to benefit from sunlight whole day. Indoor air quality is provided by high efficiency heating and cooling and air filtration systems.
555 Mission Street Building San Francisco - USA [42, 43]		ESD: Heat island effect is reduced by using materials with high light reflectivity on the roof. Total water consumption is reduced by 30% by means of the water system that uses the water effectively. The construction materials were supplied from recyclable sources.
	Height: 139.6 m / Number of Floors: 33 *Function:* Office *Certificate:* LEED Gold *Start-End Date:* 2007-2009 *Carrier system material:* Steel *Carrier system:* Steel frame	ECSD: Selecting local and recyclable construction materials that can be used for long term and providing water and energy efficiency contributed to reduce costs.
	Architectural Design: Kohn Pederson Fox & Heller Manus *Structural Design:* Louie International	SCSD: Air quality is increased by using materials that do not contain harmful components to increase indoor life quality. Open areas at the building facilitate creating visual connection with the outer environment in terms of user comfort.
Comcast Tower Philedelphia - USA [28, 44, 45]		ESD: 6100 m^3 of annual water saving is provided at the tower by using water-free toilets. Slightly textured and nonreflective glasses were selected for exterior façade. Material management plan was developed to prevent source loss and waste generation. 80 % of the wooden parts were obtained from sustainable forests.
	Height: 296.73 m / Number of Floors: 58 *Function:* Office / Certificate: LEED Gold *Start-End Date:* 2005-2008 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core + Steel frame	ECSD: Illumination costs were minimized by benefiting from the sunlight for illumination of the building and conditioning costs were minimized by using light colored materials with low emission on the exterior façade.
	Architectural Design: Robert A. M. Stern Architects Structural Design: Thornton Tomasetti	SCSD: Construction materials with toxic materials were avoided within indoors. Wide windows were selected to facilitate visual connection with outer environment.
Hearst Tower New York - USA [46, 47]		ESD: Rainwater is collected and used for the cooling system of the building. Heating and ventilation systems that provide energy efficiency are used for heating and ventilation by benefiting from the external air for a period of 75% of the year. Approximately 90% of the steel used in the construction of the building is recyclable and provided source efficiency.
	Height: 182 m *Number of Floors:* 46 *Function:* Office *Certificate:* LEED Gold *Start-End Date:* 2003-2006 *Carrier system material:* Composite *Carrier system:* Steel core +Crossed Frame	ECSD: Recyclable materials were used in the external wall and carrier system components of the building.
	Architectural Design: Foster & Partners, Gensler *Structural Design:* WSP Cantor Seinuk	SCSD: Working areas were designed close to the external façade in a way they will benefit from sunlight most efficiently. An efficient work environment is presented for users. In addition, visual connection with the outer environment can be established.

Figure 6. (Cont.) The features of tall buildings examined in the context of sustainable design

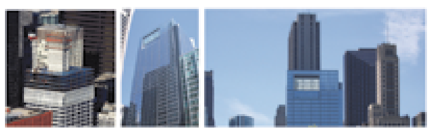
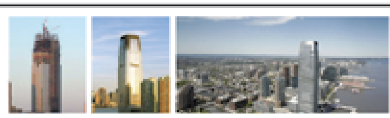
TALL BUILDINGS		SUSTAINABLE DESIGN CRITERIA
Solaire Building New York - USA [48]		ESD: Green roof method is applied on the tower to decrease the urban heat island effect and rainwater is collected on the roof. Wastewater of the building is recycled. Energy need of the building is met by the solar cells. Two thirds of the materials used in the construction of the building was supplied from the surrounding neighborhood. 93% of the waste material emerged during construction was recycled.
	Height: 85.29 m *Number of Floors:* 27 *Function:* Residence *Certificate:* LEED Gold *Start-End Date:* 2001-2003 *Carrier system material:* Concrete *Carrier system:* Reinforced concrete frame	ECSD: Selecting recyclable construction materials increased source efficiency of the building. Meeting electric need by means of solar cells reduces the energy consumption costs.
	Architectural Design: Cesar Pelli & Associates S.L.C.E Architects *Structural Design:* The Cantor Seinuk Group	SCSD: Air filtration system was used to take the indoor air quality under control. Materials that do not contain harmful components were selected for indoor areas.
One South Dearborn Building Chicago – USA [49, 50]		ESD: Alternative transportation systems were established at the surrounding of the building. A water system that uses water efficiently was selected. Illumination costs were minimized by benefiting from the sunlight for illumination of the building and conditioning costs were minimized by using light colored materials with low emission on the exterior façade. Light colored high efficiency materials were selected for façade.
	Height: 174 m / Number of Floors: 40 *Function:* Office *Certificate:* LEED Silver *Start-End Date:* 2003-2005 *Carrier system material:* Composite *Carrier system:* Reinforced concrete core+Steel frame	ECSD: Recyclable construction materials were used at the building. Saving was achieved in the costs of transportation to the site by supplying the materials used in the construction of the building from the surrounding neighbourhood.
	Architectural Design: DeStefano Keating and Partners *Structural Design:* Halvorson and Partners	SCSD: Wide windows were selected to maximize benefiting from sunlight. Users can establish visual connection with the outer environment.
30 Hudson Street Building New Jersey - USA [51]		ESD: A water system that uses water efficiently was selected for the tower. Water consumption decreased by collecting and re-using the rainwater. Certificated wooden materials were used within indoors.
	Height: 238 m / Number of Floors: 42 *Function:* Office *Certificate:* LEED *Start-End Date:* 2001-2004 *Carrier system material:* Steel *Carrier system:* Steel frame	ECSD: Economic limitations were determined by means of cost analyses by providing efficient use of the sources. Source efficiency is increased by using recyclable construction materials.
	Architectural Design: Cesar Pelli & Associates *Structural Design:* Thornton Tomasetti	SCSD: Construction materials with toxic materials were avoided and therefore indoor air quality is ensured. Visual connection with the outer environment is provided by means of wide windows.

Figure 6. (Cont.) The features of tall buildings examined in the context of sustainable design

3.1. Examination of LEED certificated tall buildings in the context of sustainable design

Compliance of tall buildings with the sustainable design criteria can be ensured by appropriate methods in the design, construction, use, and demolition phases. For tall buildings, designers should apply methods for meeting the criteria for sustainable sites, water efficiency, energy and atmosphere, materials and resources in terms of *ecological sustainable design;* the criteria for efficient use of resources and low operating cost in terms of *economical sustainable design;* and the criteria of indoor environmental quality and innovation and design process in terms of *sociocultural sustainable design.*

In this context, the application of these criteria and methods on 13 LEED certificated buildings that are now in use were examined. The location, height, number of floors, function, type of LEED certificate, project start and end date, carrier system material and type, architectural designers and structural designers, are presented in Figure 6. The sustainable design criteria applied for these buildings are given in Table 1.

Table 1. Evaluation table of sustainable design criteria for the studied LEED certificated tall buildings

Sustainable Design Criteria			The Examined LEED certificated tall buildings															
			Bank of America Tower	The Visionaire Building	Taipei Financial Center	Condé Nast Building	The Helena Building	Eleven Times Square Building	7 World Trade Center	555 Mission Street Building	Comcast Tower	Hearst Tower	Solaire Building	One South Dearborn Building	30 Hudson Street Building	Total points	Section points	Section percentage
ESD	ESD1	ESD1.1	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD1.2	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD1.3	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD1.4	2	2	2	2	2	2	2	2	2	2	1	2	1			
		ESD1.5	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD1.6	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD1.7	2	2	2	2	2	2	2	2	2	2	2	2	2			
	ESD2	ESD2.1	2	2	1	2	2	2	2	2	2	1	1	1	1			
		ESD2.2	2	2	2	1	1	1	1	1	1	2	2	2	2			
		ESD2.3	2	2	2	1	2	2	2	2	2	2	2	2	2			
		ESD2.4	2	2	2	1	2	2	1	2	1	2	2	2	2			
	ESD3	ESD3.1	2	2	2	2	2	0	0	0	2	0	2	0	2			
		ESD3.2	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD3.3	0	2	2	2	1	0	0	0	2	1	2	1	2			
		ESD3.4	2	2	2	2	2	2	2	2	2	2	1	2	1			
		ESD3.5	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD3.6	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD3.7	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD3.8	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD3.9	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD3.10	2	2	2	2	2	0	2	0	2	1	2	1	2			
	ESD4	ESD4.1	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD4.2	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD4.3	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD4.4	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD4.5	2	2	2	1	1	2	2	1	1	2	2	2	2			
		ESD4.6	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ESD4.7	2	2	2	2	2	2	2	2	2	2	2	2	2	Total points	Section points	Section percentage
POINTS			54	56	55	52	53	49	50	48	53	51	53	43	38	655	728	90 %
ECSD	ECSD1	ECSD1.1	2	2	2	2	2	2	2	2	2	2	2	2	2			
		ECSD1.2	2	2	2	2	2	2	2	2	2	2	2	2	1			
	ECSD2	ECSD2.1	2	2	2	2	2	2	2	1	2	2	2	2	1			
		ECSD2.2	2	2	2	2	2	2	2	2	2	2	2	2	0			
		ECSD2.3	2	2	2	2	2	2	2	1	2	2	2	2	2	Total points	Section points	Section percentage
POINTS			10	10	10	10	10	10	10	8	10	10	10	10	6	124	130	95 %
SCSD	SCSD1	SCSD1.1	2	2	2	2	2	2	2	2	2	2	2	2	2			
		SCSD1.2	2	2	2	2	2	2	2	2	2	2	2	2	2			
		SCSD1.3	2	2	2	2	2	2	2	2	2	2	2	2	2			
		SCSD1.4	2	2	2	2	2	2	2	2	2	2	2	2	2			
	SCSD2	SCSD2.1	2	2	2	2	2	2	2	2	2	2	2	2	2			
		SCSD2.2	2	2	2	2	2	2	2	2	2	2	2	2	0			
		SCSD2.3	2	2	2	2	2	2	2	2	2	2	2	2	2			
		SCSD2.4	2	2	2	2	2	2	2	2	2	2	2	2	2	Total points	Section points	Section percentage
POINTS			16	16	16	16	16	16	16	16	16	16	16	16	14	206	208	99 %

3.2. Evaluation of examined LEED certificated tall buildings in the context of sustainable design

In this chapter, an evaluation method is proposed to assess efficiency of LEED certificated tall buildings analyzed in Chapter 3.1. The evaluation criteria of the proposed method are based on sustainable design criteria given in Chapter 2.2, and are scored objectively. For the scoring, 2 points are allocated for application of sustainable design criteria, 1 point for partial application of criteria, and 0 points for non-application of design criteria. The efficiency of tall buildings is evaluated in % in terms of sustainable design based on evaluation criteria. This evaluation is given in the evaluation table presented in Table 1. According to the evaluation table presented in Table 1, the success of the LEED certificated tall buildings in the context of evaluation criteria is 90 % for ecological sustainable design, 95 % for economical sustainable design, and 99 % for sociocultural sustainable design. According to results of the evaluation, ecological, economical and sociocultural sustainable design criteria are largely resepcted in the examined LEED certificated tall buildings. Figure 7 shows the evaluation graphic of LEED certificated tall buildings in the context of sustainable design.

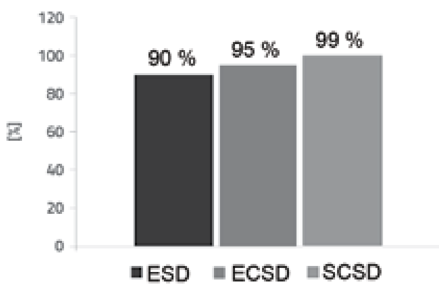


Figure 7. Graphic presentation of sustainable design criteria for LEED certificated tall buildings

3.3. Findings and discussion

In this chapter, LEED certificated tall buildings, examined in Chapter 3.1 and evaluated by the method proposed in Chapter 3.2, are compared in terms of ecological, economical and sociocultural sustainable design criteria. This comparison is based on the data given in Table 1. Evaluation graphs were drawn and comparison tables were formed for each design criteria for the examined tall buildings. In this comparison table, the success of LEED certificated tall buildings was evaluated in terms of ecological, economical, and sociocultural sustainable design criteria. Tall buildings were evaluated separately in terms of ESD, ECSD and SCSD criteria in Table 2 and the compliance of each building to these criteria was expressed in %.

The findings related to the evaluation graphics included in Table 2 for each tall building separately can be interpreted as follows:

- ESD1 criteria were applied at Solaire, One South Dearborn and 30 Hudson Street Buildings with 93 %; and 100 % at other buildings. It is observed that ESD2 criteria were applied with 100 % at Bank of America Tower and Visionaire Building; 88 % at Taipei Financial Center, Helena, Eleven Times Square, 555 Mission Street, Solaire Buildings and Hearst Tower; 75 % at 7 World Trade Center and Comcast Tower; and 63 % at other buildings. ESD3 criteria were applied with 100 % at Visionaire Building, Taipei Financial Center, Condé Nast Building and Comcast Tower; 95 % at Helena and Solaire Buildings; 90 % Bank of America Tower; 80 % at 7 World Trade Center and Hearst Tower; 70 % at Eleven Times Square, 555 Mission Street and One South Dearborn Buildings; and 55 % at 30 Hudson Street Building. When ESD4 criteria are examined, they were applied at 100 % at Bank of America Tower, Visionaire Building, Taipei Financial Center, Eleven Times Square Building, 7 World Trade Center, Hearst Tower and Solaire Building; 93 % at Condé Nast Building, Helena Building, 555 Mission Street Building and Comcast Tower; 79 % at One South Dearborn Building; and 64 % at 30 Hudson Street Building. It is observed that ECSD1 criteria were applied at 75 % 30 Hudson Street Building and 100 % at other buildings; and ECSD2 criteria were applied at 67 % at 555 Mission Street Building, 50 % at 30 Hudson Street Building and 100 % at other buildings. It is observed that SCSD criteria were applied at 100 % at all tall buildings except 30 Hudson Street Building with 99 %.
- It is determined for the examined tall buildings that application ratio of the ECSD criteria is more than the ratio of ESD criteria; and application ratio of the SCSD criteria is more than the ratio of ESD and ECSD criteria. As mentioned in Chapter 3.1, Bank of America Tower, The Visionaire Building and Taipei Financial Center have LEED Platinum certificate; Condé Nast Building, The Helena Building, Eleven Times Square Building, 7 World Trade Center, 555 Mission Street Building, Comcast and Hearst Tower, and Solaire Building have LEED Gold certificates; One South Dearborn Building has LEED Silver certificate; and 30 Hudson Street Building has LEED certificate (See. Figure 6). These tall buildings with different LEED certificates were evaluated in terms of ESD, ECSD and SCSD criteria in Table 3 and application success of these tall buildings were given in %.

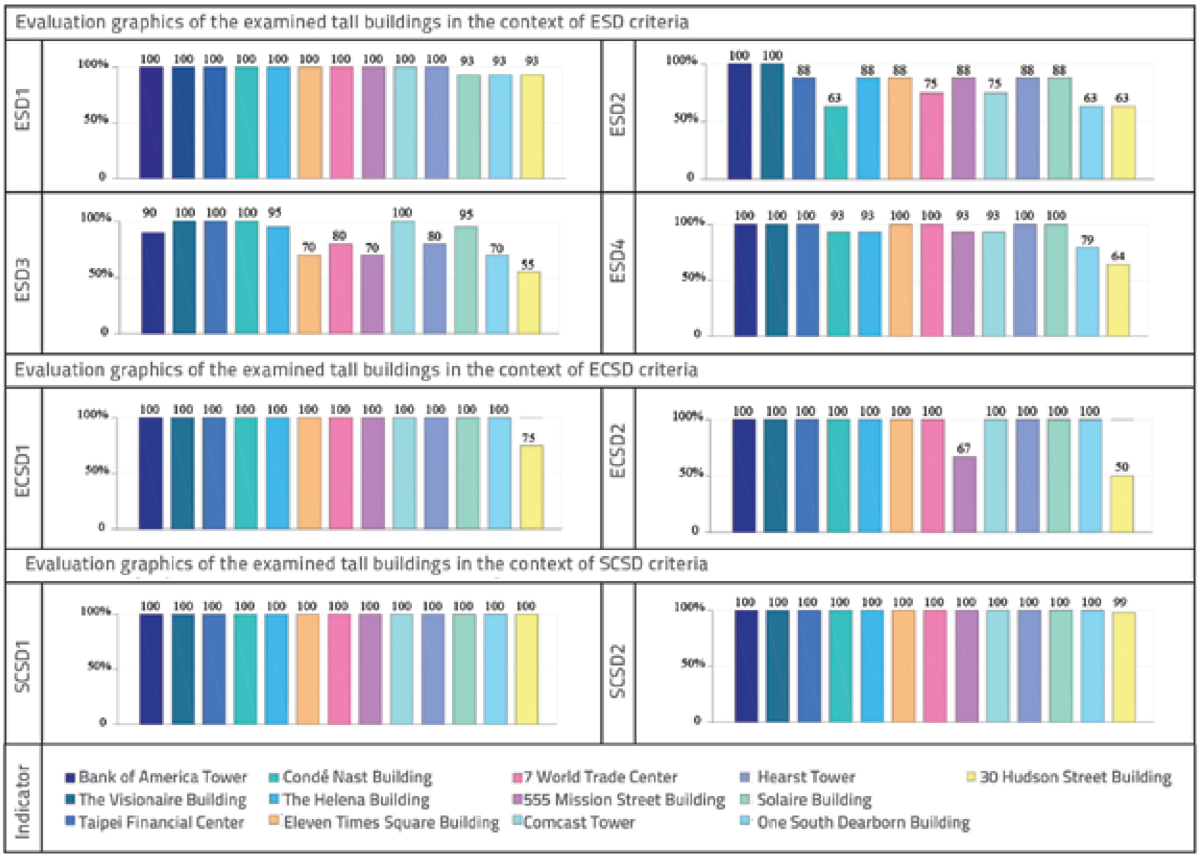
The findings related to the evaluation graphics included in Table 3 for each sustainable design criteria can be interpreted as follows:

- Visionaire Building, Helena Building and Solaire Building are residential buildings, and the other examined buildings are office buildings as mentioned in Figure 6. It's observed that ECSD1, ECSD2, SCSD1, SCSD2 criteria were applied with 100 % at residential buildings. On the contrary, ECSD1 criteria were applied with 75 % and ECSD2 with 50 % at 30 Hudson Street Building, and ECSD2 criteria were applied with 67 % at 555 Mission Street Building which are used as office buildings. According to graphics from Table 3, the ratios for

Table 2. Comparison of ESD, ECSD and SCSD criteria applied for tall buildings

Tall Buildings	ESD				ECSD		SCSD	
	ESD1	ESD2	ESD3	ESD4	ECSD1	ECSD2	SCSD1	SCSD2
Bank of America Tower	100%	100%	90%	100%	100%	100%	100%	100%
The Visionaire Building	100%	100%	100%	100%	100%	100%	100%	100%
Taipei Financial Center	100%	88%	100%	100%	100%	100%	100%	100%
Condé Nast Building	100%	63%	100%	93%	100%	100%	100%	100%
The Helena Building	100%	88%	95%	93%	100%	100%	100%	100%
Eleven Times Square Building	100%	88%	70%	100%	100%	100%	100%	100%
7 World Trade Center	100%	75%	80%	100%	100%	100%	100%	100%
555 Mission Street Building	100%	88%	70%	93%	100%	67%	100%	100%
Comcast Tower	100%	75%	100%	93%	100%	100%	100%	100%
Hearst Tower	100%	88%	80%	100%	100%	100%	100%	100%
Solaire Building	93%	88%	95%	100%	100%	100%	100%	100%
One South Dearborn Building	93%	63%	70%	79%	100%	100%	100%	100%
30 Hudson Street Building	93%	63%	55%	64%	75%	50%	100%	99%

Table 3. Comparison of tall buildings in the context of ESD, ECSD and SCSD criteria



both residential and office buildings are not so different from each other. Consequently, it can be stated that the function of the building does not affect the application of sustainable design criteria for tall buildings.

4. Conclusions

In line with the aim of this article, a guiding framework is presented in form of a compilation and summary of the data related to sustainable tall buildings. Ecological, economical and sociocultural sustainable design criteria were determined to create this guiding framework. The application of these criteria at 13 LEED certificated tall buildings were examined, and the efficiency of tall buildings was evaluated in the context of the proposed objective evaluation for ecological, economical and sociocultural sustainable design, in line with the data obtained as a result of the examination. It was observed as a result of the evaluation of the LEED certificated tall buildings that ESD criteria were applied with a ratio of 90 %, ECSD criteria with a ratio of 95 %, and SCSD criteria with a ratio of 99 %. Again according to the evaluation results, the compliance with sustainable design criteria for LEED Platinum certificated tall buildings is 99 %; for LEED Gold certificated tall buildings 97 %; for LEED Silver certificated tall buildings 92 %; and for LEED certificated tall buildings 76 %. These high ratios have great importance in terms of creating an example for the importance of sustainable design and certificate systems for tall building design that will be implemented in Turkey as well as all over the world.

The number of tall buildings in Turkey has been rapidly increasing for reasons such as user needs that have varied and increased in recent years, development of construction technologies, increase of density in urban centers, and increase in the value of land. However, the number of sustainable tall buildings is still not sufficient. Therefore, sustainable design criteria and certificate systems that are implemented globally in the design of tall buildings should also be promoted in Turkey. In this context, the relations built in this article should be adopted as sustainable design approach by all stakeholders operating in the building sector. In addition, this approach should be supported with scientific studies, education programs and laws and regulations; and some enforcements should be imposed by government authorities to enable proper application of sustainable design criteria for tall buildings. Designers should contribute to the increase in ecological awareness in the society with example structures and educational establishments. Appropriate information should be disseminated by means of undergraduate/graduate courses, seminars and conferences. Moreover, the emphasis should be placed on the actions aimed at increasing the number of experts on certification systems.

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