# Towards an Ecological Design
# Sustainable Building materials "Standards & Determinants"

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**Abstract:**
Recently, buildings industry technology has widely developed including all levels, starting from the first design phases, then construction phases and systems till the end of the duration of the building. However, that industry has witnessed a number of failing aspects that are not only confined to the consumption of energy sources by building materials, but they also include the side effects that have been caused by those materials on the surrounding environment in the form of pollution, consumption of the preliminary energy sources, negative health effects on users, and so on.
Therefore, it was a must to pay attention to the steps of developing and modernizing that industry in a sufficient way that protects the environment generally and the user specifically. The most important step for that purpose is to innovate and modernize the ecological buildings as one of the fundamental and basic constituents of the green architecture.
Moreover, the research aims at defining the required standards and strategies for evaluating and determining the sustainability extent of the building materials through their different phases as a main step contributing in the development of the ecological buildings design and, thus, enabling the designer to choose the most suitable of those materials. We infer that the sustainability of materials has its relative significance or each material during its phases with the building, starting from the pre-building phase, then building phase till post-building phase. The impact of substance manufacturing has a clear impact on the achievement of eco-design as well as the operation phase. In spite of the relative significance of the materials' sustainability, yet this does not mean that we should not evaluate the system of the sustainability of the whole building through using the evaluation methods that are adopted internationally.
The research conclude the basic criteria for the ecological construction materials evaluation, a check list has been designed for these materials included the distribution of the percentage of design according to the relative importance of each phase and each standard, so it can be concluded Overall Rating article taking into consideration the importance of each stage and all the standard for its impact on the overall evaluation

**Keywords:**
Sustainable building materials – ecological materials – sustainable design – sustainability - green building materials

## 1- Introduction: Importance of Sustainable Building Materials:

The trend of the sustainable architecture is defined as the trend that meets the present needs of the users without prejudice to their future needs. Interestingly, architecture is considered a unique field in the field of the sustainable development through the conscious use of the natural sources and the management of the building in order to contribute in conserving the surrounding environment.
Choosing the sustainable building materials is considered one of the most important and simplest means that enable the designer to apply the basics and strategies of the sustainable principles in architecture. Yet, this does not spread sufficiently amongst the designers, and thus, they depend only on differentiating between building materials in respect of those materials that cost less in their manufacture and production regardless of their properties and ecological cost.
Furthermore, the study aims at determining the basics and strategies of the sustainable materials and identifying their properties and advantages in order to have a referential list through which we can evaluate building materials and differentiate between their alternatives to select the most suitable one for the sustainable buildings.

## 2- Phases of Building Materials[1]:

### 2-1 Preface:

Implementing and constructing any building during its duration passes through a number of successive phases, starting from the stage of the primary design, then the final design till the end of the building's duration.
In a parallel way, the building materials pass through a number of successive phases that coincident with the building phases till the post-building phase, Figure No. (1). the building materials can be divided in accordance with the building phases into 3 main sections as follows:

A- Pre-construction phase.
B- Building construction & use phases.
C- Post-building phase.

The main objective and goal from this division is the possibility of defining cost or the ecological effect because the use of these materials in each phase as well as evaluating them to apply the ecological differentiation and, thus, select amongst the multiple building materials alternatives.

### 2-2 Pre-Construction Phase:

This phase includes all the steps of producing and preparing materials till the pre-building phase and the installation of those materials into the building; i.e. this phase includes the exploration and extracting raw materials, their manufacture, packaging, then transporting them to the building site and preparing them for building installation.

[1] Christoph Kippenberger, **Materials Flow and Energy Required for The Production of Selected Mineral Commodities-Summary and Conclusions**, Geologisches Jahrbuch, Reihe H, Sonderheft, Germany, 2009.

This stage, also, has its own unique nature, together with its significant effect on the surrounding environment whether positive or negative, thus it must be accompanied by studying and evaluating the ecological effect of that stage from the beginning.
The most important factors that influence the surrounding environment during this stage are the following:

- Defining, choosing and extracting raw materials.
- Methods, ways and mechanism of manufacturing.
- Relationship between the building and the manufactured materials.

Depending, in this phase, on the limited and non-renewable environmental resources is considered one of the most influential factors that have a harmful ecological effect on environment. For example, for extracting and producing raw iron, these operations are performed by using limited & non-renewable environmental resources from layers of iron and rocks inside earth and the manufacturing operation causes wastes that are harmful for the environment.

On the other hand, the resources may be renewable theoretically only. For instance, wood is considered one of the renewable resources in the plants and forests with their various types, provided that the renewing rate is more than or equal to the human consumption rate. But this does not conform to the actual rates in which some kinds of wood need more than 80 years to grow and be available in the environment.
The negative effect and the ecological destruction on the surrounding environment as a result of the negative selection of raw materials can be determined through 4 main points as follows:

A- Destruction of the habitat of the living creatures.
B- Damage of the surrounding environment.
C- Soil & water pollution.
D- Air pollution.

*** construction materials classifications as per building construction phases:**
**1- Excavation & backfilling materials.**
**2- Civil construction materials.**
**3- Adhesives, chemicals & insulation layers.**
**4- Internal finishing materials.**
**5- External finishing materials.**
**6- Wooden & metal works.**
**7- Doors & windows.**
**8- Sanitary fixtures.**
**9- Electrical Fixtures.**
**10- Exterior materials.**
**11- Other materials.**

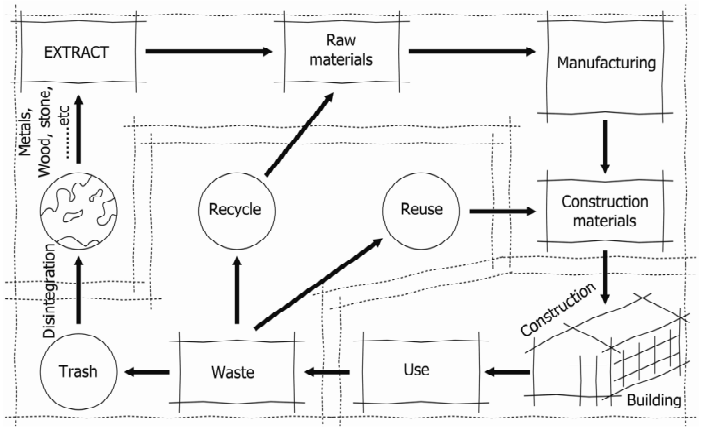


**Figure (1): Building materials stages**

### 2-2-1 Destruction of Living Creatures' Habitat:

Living creatures and natural plants form an integral environmental system that is in conformity with the environment. So, any random and haphazard interference by man into this system by extracting the natural materials or removing them in a random way destructs and affects the balance of that system, and thus, destructs the natural environment. For example, plants contribute greatly in regulating the relative humidity, purifying air from all pollutants and generating the necessary oxygen for living creatures as well as eliminating carbon dioxide. So, any interference and random removal for those plants are considered factors that prejudice to that system and its previous positive sides.

### 2-2-2 Damage of the Surrounding Environment

Extraction and usage of the natural materials greatly lead to the damage and end of the natural environment. For instance, the fertile land was exposed to destruction and erosion before the legal prohibition of making the burned red bricks from the silt of farmlands during 1980s in Egypt.

### 2-2-3 Soil & Water Pollution

Manufacturing of some building materials causes some waste that is harmful for the environment. That waste may cause pollution for the surrounding soil, and thus, pollution of the underground water and other multiple environmental elements.

### 2-2-4 Air Pollution

Burning molecules of raw materials during the manufacturing phases and transportation leads to pollution of the surrounding air, especially by carbon monoxide and carbon dioxide that are harmful for living creatures, in addition to sulphur dioxide and nitrous oxide that cause acid rain that affects negatively the buildings and the surrounding plants and water life.

## 2-3 Building construction & operation phase:

This phase starts with the execution and installation of the building materials into the building, after which operation and maintenance phase starts during the duration phases of the building before the post-building phase.

### 2-3-1 Construction Phase:

The main goal of this phase is regarding the selection of executive materials and techniques that are distinguished with minority and possibility of reusing the execution and building waste by recycling them and preventing the harmful waste as much as possible.

### 2-3-2 Operation & Maintenance Phase

During this phase, it's a must to depend on the materials and the necessary energy sources for operation and maintenance. Those materials and sources must not be harmful, pollutant or cause any negative effects on the environment or the users of the internal vacuums.

## 2-4 Post-building Phase:

This phase is considered one of the important phases that influence the evaluation of the sustainability of the building materials. After the end of the post-building phase or

the end of the duration of the building materials, there are a number of possibilities for those materials as follows:

**2-4-1 Reuse:**
This means that it's possible to reuse those materials in other buildings. In that case, it's important to choose materials that have long duration and efficient. For example, it's possible to reuse installation materials for the metal institutions can be reused. Those materials contribute in conserving the consumed energy or power in the extraction and manufacturing that may cause harmful effects on the surrounding environment, in addition to their conservation of the environmental resources, especially the non-renewable.

**2-4-2 Recycle:**
These materials are considered one of the raw material sources; as they can be reentered in the manufacturing and processing phases to get a new product that can be reused in new buildings.

**2-4-3 Waste:**
It's a must to pay more attention to materials that have quick organic dissolving properties and that are friendly to the environment in order to conserve lands and the surrounding environment after the end of the duration of the materials.

## 3- Properties & Advantages of Sustainable Building Materials:

### 3-1 Preface: Standards of Sustainable Building Materials:

Depending on the principles and standards of the sustainable buildings and on what previously mentioned, the sustainable building materials are characterized by a number of determinants, standards and properties that distinguish them from the others by the sustainability principles. These standards have been divided into 3 main sections or divisions that coincident with the phases of using the materials in the buildings that were previously mentioned, these are as follows[2]:

**A- Manufacturing Process (MP):**
This process is done coincidentally with the pre-building phase.

**B- Building Operation (BO):**
This is done coincidentally with building phase.

**C- Waste Management (WM):**
This is done coincidentally with post-building phase.

Table No. 1 shows the standards and properties of the sustainable building materials during the previous building duration. The research study through the following points deals with showing and analyzing those standards and the most important features of each standard.

### 3-1-1 Manufacturing Process (MP):

**1- Waste Reduction (WR):**

[2] Jong-Jin Kim, Qualities, Use and Examples of sustainable building materials, National pollution prevention center, 2003.

Manufacturing waste covers all excessive products that are produced during the different manufacturing processes like: shaping/cutting/finishing/……etc. or from the faulted products or products that are not conformed to the specifications. The goal is to make the manufacturing process more efficient through reducing or limiting waste by recycling them or reusing them in other industries. For example, iron slag that is derived from the manufacturing processes of iron can be used in manufacturing some kinds of bricks of good thermal properties.

**Table (1): Standards and properties of the sustainable building materials[3]:**

| (WM)<br>Waste Management | (BO)<br>Building Operations | (MP)<br>Manufacturing Process |
|---|---|---|
| **Reu**sability **(RU)** | **R**eduction in **C**onstruction **W**aste **(RCW)** | **W**aste **R**eduction **(WR)** |
| **R**ecyclability **(R)** | **E**nergy **E**fficiency **(EE)** | **P**ollution **P**revention **(PP)** |
| **B**iodegradability **(B)** | **W**ater **T**reatment / **C**onservation **(WTC)** | **R**ecycled **C**ontent **(RC)** |
| | Use of **N**on-**T**oxic Materials **(NT)** | **E**mbodied **E**nergy **R**eduction **(EER)** |
| | **R**enewable **E**nergy **S**ystem **(RES)** | Use of **N**atural **M**aterials **(NM)** |
| | **L**onger **L**ife **(LL)** | |

**2- Pollution Prevention (PP):**

Types of pollution as a result of manufacturing and transportation processes are various and different. For example:

- Polluting air by toxic gases.
- Noise pollution.
- Polluting water by waste and acid rain.
- Polluting air by burning fuel gases during manufacturing & transportation processes, especially by carbon dioxide.
- Polluting soil by manufacturing waste.

The aim is to limit and prevent pollution that is caused by manufacturing processes. The most important example is the possibility of remanufacturing or recycling the manufacturing waste that are harmful for the environment, like processing water that is used in the manufacturing processes in a way known as grey water in order to reuse it for the purposes of agriculture and the like.

**3- Recycled Content (RC):**

If the product is characterized by a great percentage of recycled materials, this is considered a helping factor in protecting the surrounding environment from pollution, rationalizing the consumed energy and protecting the limited environmental resources.

**4- Embodied Energy Reduction (EER):**

Manufacturing energy constitutes the consumed energy, starting from the phases of extracting raw materials, manufacturing them and packaging them as a product to the

[3] Ibid.

energy that is consumed for transporting the materials to the building site. The aim is to limit and reduce the consumed energy' especially the non-renewable energy to conserve the energy sources in the environment in any phase of the manufacturing processes; such as producing materials locally in order to reduce the transportation energy, for instance.

**5- Use of Natural Materials (NM):**
Natural materials require techniques, manufacturing processes and processing less than the synthetic materials, thus they contribute in conserving the consumed energy significantly, together with conserving and protecting the surrounding environment from pollution.

**3-1-2 Building Operation:**

**1- Reduction in Construction Waste (RCW):**
Regarding the direct relationship between the design and the fixed measuring dimensions for building materials contributes greatly and significantly in limiting and reducing the waste of building materials that result from construction and cutting.

**2- Energy Efficiency (EF):**
Characteristics of building materials contribute in defining the consumed energy inside buildings through several measurements upon which building materials characteristics are defined. For example: R-Value, Shading Coefficient, Luminous Efficiency, and Fuel Efficiency.
The target is to choose materials of positive environmental characteristics that can reduce the consumed energy inside building; especially during the building operation.

**3- Water Treatment & Conservation (WTC):**
Some materials require a huge consumption of water during the building phase or building operation. The target is to choose materials reducing the consumed water through two main factors:

A- Decrease the water required for the building operation and building phase.
B- Decrease the water required to be treated after being used in the building operation or building phase as a co – factor for maintaining chemicals used for treatment and the consumed energy as well.

**4- Use of Non-toxic Materials (NT):**
There are many toxic materials inside the environment that can harm internal spaces users. There is no doubt that these materials should be prohibited definitely such as asbestos, red lead and the like which have been internationally prohibited in all building processes.

**5- Renewable Energy Systems (RES):**
Several materials are based on the renewable energy systems such as wind, solar radiation and bio power; particularly during the building operation. This contributes significantly in benefiting from the renewable energy advantages, preventing pollution and maintaining sources of the non – renewable energy. Some of these materials are solar heaters, PV-modules and the like.

**6- Longer Life (LL):**
Materials of longer life have several advantages, contributing significantly in achieving the sustainability; for example:

A- Providing raw materials.
B- Reducing energy consumed in manufacturing, execution and transportation.
C- Reducing the costs especially depreciation of assets.
D- Possibility of using these reusable materials after the building life is being expired.

### 3-1-3 Waste Management Phase (WM):

**1- Possibility of Re – Use (RU):**
Some materials are characterized by hardness and longer life; so that they can be reused after the building life is being expired. This contributes in the environment maintenance with respect to raw materials / consumed energy / …. Etc. By being dismantled easily from the existing building and reinstalled in the other building.

**2- Possibility of Recycle (R):**
Possibility of material recycle is determined according to the possibility of material use after the building life is being expired as a source for producing new materials, for example metal structures are considered recyclable materials that can be dismantled easily from the building and remanufactured for other new buildings.

**3- Possibility of Material Decay Naturally:**
Some materials cannot be reused or recycled again after the building life is being expired, so that these materials should be chosen carefully and returned back to the environment in their initial form after being expired through decay. This decay should be conducted quickly to avoid any harm substances being released to the environment. For example, organic substances are decayed quickly unlike the iron that takes longer time for being decayed; releasing toxic and harmful materials as well.

## 4- Matrix of Building Materials Sustainability:

Table No. 2 shows matrix of materials sustainability that is considered one of the important means for evaluating the material sustainability, choosing and comparing between the different alternatives of materials. This matrix is based on table of the sustainable building materials characteristics and standards as above mentioned. Moreover, this matrix is based, during evaluation of materials sustainability, on fulfilling the sustainability characteristics for all aforementioned building materials phases or not.

**Table (2): Building Materials Sustainability matrix:**

| (WM) | (BO) | (MP) |
|---|---|---|
| (RU) | (RCW) | (WR) |
| (R) | (EE) | (PP) |
| (B) | (WTC) | (RC) |
| | (NT) | (EER) |
| | (RES) | (NM) |
| | (LL) | |
| **Material name: …….** | | |

However, this matrix disregards the relative weight for each element; assuming equality of their relative weight. Thus, another evaluation matrix should be developed to indicate the effect of relative weight for each phase and element.

Examples for sustainability matrix of different materials used in several construction works shall be as follows:

| (WM) | (BO) | (MP) |
|---|---|---|
| (RU) | (RCW) | **(WR)** |
| **(R)** | (EE) | (PP) |
| (B) | (WTC) | **(RC)** |
| | (NT) | **(EER)** |
| | (RES) | (NM) |
| | **(LL)** | |
| **Recycled asphalt for road** | | |

| (WM) | (BO) | (MP) |
|---|---|---|
| **(RU)** | (RCW) | **(WR)** |
| **(R)** | (EE) | (PP) |
| (B) | **(WTC)** | **(RC)** |
| | **(NT)** | **(EER)** |
| | (RES) | (NM) |
| | **(LL)** | W |
| **Pavement tiles with agriculture** | | |

| (WM) | (BO) | (MP) |
|---|---|---|
| **(RU)** | (RCW) | (WR) |
| **(R)** | (EE) | (PP) |
| **(B)** | (WTC) | **(RC)** |
| | **(NT)** | (EER) |
| | (RES) | **(NM)** |
| | **(LL)** | |
| **Metal Structure** | | |

| (WM) | (BO) | (MP) |
|---|---|---|
| (RU) | (RCW) | **(WR)** |
| (R) | **(EE)** | (PP) |
| (B) | (WTC) | (RC) |
| | (NT) | (EER) |
| | (RES) | (NM) |
| | **(LL)** | |
| **Reinforced concrete** | | |

| (WM) | (BO) | (MP) |
|---|---|---|
| (RU) | (RCW) | **(WR)** |
| **(R)** | **(EE)** | **(PP)** |
| (B) | (WTC) | **(RC)** |
| | **(NT)** | (EER) |
| | (RES) | (NM) |
| | (LL) | |
| **Polystyrene** | | |

| (WM) | (BO) | (MP) |
|---|---|---|
| **(RU)** | (RCW) | (WR) |
| (R) | **(EE)** | (PP) |
| (B) | (WTC) | **(RC)** |
| | **(NT)** | (EER) |
| | (RES) | **(NM)** |
| | **(LL)** | |
| **Cement blocks** | | |

## 5- Suggestion of a Reference List for Sustainable Building Materials:

Through the previous study, building materials are divided into 3 main phases:

- Manufacturing Process (MP).
- Building Operation (BO).
- Waste Management (WM).

For taking the relative weights into consideration, the most important strategies for each phase should be determined to propose an ecologic evaluation model for building materials, their sustainability and their characteristics through which we can compare and choose between them and other building materials. This model takes into consideration all elements and basics of the sustainable design as well as the suitable relative weights.

All relative weights are included in this matrix for guidance; however these weights as well as evaluation elements could be changed according to the surrounding circumstances and this strategy's significance to the building.

| **Sustainability Basics Evaluation model for Building Materials** | | | | |
|---|---|---|---|---|
| **Project Name:** …… | | **Location:** …… | | |
| **Material Name:** ……..... | | **Category of Material as per Building Phase:** …… | | |
| **Material Code:** ……..… | | **Suppliers:** …… | | |
| **Raw Materials of which building material is made**: …… | | | | |
| **1- Manufacturing Process:** | | **0** | **1** | **2** |
| **1** | Percentage of recyclable and reusable manufacturing wastes. | < 15% | 25: 65% | > 65% |
| **2** | Possibility of the organic decay for the harmful manufacturing wastes. | Impossible | ----- | Possible |
| **3** | Percentage of environmentally harmful and polluted manufacturing wastes. | < 15% | 25: 65% | > 65% |
| **4** | Are there polluted and harmful emissions during the manufacturing process? | Yes | ----- | No |
| **5** | Is there noise pollution during the manufacturing processes? | Yes | ----- | No |
| **6** | Is there polluted water resulting from the manufacturing process? | Yes | ----- | No |
| **7** | Possibility of water treatment to be reused. | Impossible | ----- | Possible |
| **8** | Percentage of recyclable materials of which the product is made. | < 15% | 25: 65% | > 65% |
| **9** | Percentage of manufacturing energy when recyclable materials are used, in comparison with the same product free of these materials. | < 15% | 25: 65% | > 65% |
| **10** | Sources of energy used in raw materials extraction. | Primary Energy | ----- | Renewable Energy |
| **11** | Sources of energy used in manufacturing. | Primary Energy | ----- | Renewable Energy |
| **12** | Are materials used in manufacturing local or not? | Imported | Local / Imported | Local |
| **13** | Distance between the building and place of manufacturing. | >75Km | 50: 75Km | <50Km |
| **14** | Availability and development of the used raw materials. | Unavailable | ----- | Available |
| **15** | Are the used raw materials derived naturally from the surrounding environment? | No | Some | Yes |
| | | | | |
| | **TOTAL** | | | |
| | | | **15** | **30** |
| **Total Material Evaluation in Manufacturing Process ---------- of Total 30 Points** | | | | |

| 2- Building Operation Phase: | | 0 | 1 | 2 |
|---|---|---|---|---|
| 1 | Percentage of recyclable building wastes. | < 15% | 25: 65% | > 65% |
| 2 | Are unrecyclable building wastes environmentally polluted? | Yes | ----- | No |
| 3 | Possibility of the organic decay for these wastes. | Impossible | ----- | Possible |
| 4 | Are there positive environmental characteristics of materials; saving the consumed energy as of lighting / temperature / …… etc? | No | ----- | Yes |
| 5 | Is there polluted water resulting from the building operation? | Yes | ----- | No |
| 6 | Possibility of water treatment to be reused. | Impossible | ----- | Possible |
| 7 | Sources of energy used in operation. | Primary Energy | ----- | Renewable Energy |
| 8 | Does material contain any polluted or toxic substances harming the user? | Yes | ----- | No |
| 9 | Are there any harmful gases or emissions resulting from the building operation? | Yes | ----- | No |
| 10 | Percentage of the product life compared to the building life. | Smaller | Equal | Bigger |
| 11 | Costs of operation " Labor / Energy / …… etc" compared with the costs of building phase. | High | Suitable | Low |
| 12 | Costs of maintenance " Equipment / Renovation / …… etc" compared with the costs of building phase. | High | Suitable | Low |
| | | | | |
| | **TOTAL** | | **12** | **24** |

**Total Material Evaluation in Building Operation ---------- of Total 24 Points**

| 3- Wastes Management Phase: | | 0 | 1 | 2 |
|---|---|---|---|---|
| 1 | Possibility of using the product in another building after the first building life is being expired. | Impossible | ----- | Possible |
| 2 | Cost of dismantling the product in proper condition to be reinstalled in another building; compared to its first production costs. | High | Suitable | Low |
| 3 | Percentage of the recyclable materials for being reused in another product. | < 15% | 25: 65% | > 65% |
| 4 | Consumed energy for recycling, remanufacturing and reusing these materials. | Primary Energy | ----- | Renewable Energy |
| 5 | Are wastes of unrecyclable materials environmentally polluted? | Yes | ---- | No |
| 6 | Possibility of the organic decay for these materials. | Impossible | ----- | Possible |
| 7 | Are these materials are decayed quickly or not? | Months | Weeks | Days |
| 8 | Are there any toxic substances resulting from this organic decay? | Yes | ----- | No |
| | **TOTAL** | | **8** | **16** |

**Total Material Evaluation in Waste Management Phase---------- of Total 16 Points**

**Total Material Evaluation from the Prospective of Sustainability**
**---------- of Total 70 Points**

**Total Percentage of Material Evaluation from the Prospective of Sustainability**
**---------- %**

**Observations and recommendations:**
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……
……

## 6- General Conclusion:

1- Phases of building materials that affect of building sustainability are divided into 3 main phases: Pre – Building Phase – Building Phase – post – Building Phase.
2- Each phase has its relative importance to the building for achieving the sustainability.
3- Identification of material sustainability using the sustainability matrix is inaccurate; it rather requires the relative weight of each element.
4- The relative weight can be identified initially for each material by specifying all strategies and factors completing each phase.
5- Increasing the strategies of each phase affects positively on its relative importance during evaluation and comparison.
6- Through the initial proposal of matrix, we found that the relative weight of material sustainability during manufacturing and building phases is higher than the relative importance for post – building phase.
7- Achieving materials sustainability does not mean necessarily the sustainability of building as a whole. Moreover, it does not replace the approved International Valuation Standards for measuring the buildings sustainability such as LEED and the other assessment tools.

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