



Principles of assessment and improvement of construction systems environmental sustainability in Iran (By Life cycle Numerical Parametric Measurement Approach)

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Abstract

Today, due to the rapid growth of population, development of the construction industry is a necessity. All around the world, new subjects such as sustainable development, environmental pollution, conservation of resources, and reduction of CO₂ emission have become the most important research topics among the scientific societies. In recent years, especially after 1997, new tools were invented to assess the building environmental impacts, including total life cycle, from production to demolition. National regulation of the buildings in Iran has a complete chapter on how to calculate and control energy consumption of the buildings during their operation phase, but unfortunately, construction and demolition phases are totally neglected. Absence of a practical regulation to control unpleasant impacts of the construction and demolition phases of a building could cause unsustainable development, as a silent crisis is currently happening and is going to appear in next decades when the buildings gradually reach the final phase of their life cycles. This paper will try to draw a framework for assessment of the environmental impacts of buildings during their entire life cycle using the ISO standards for life cycle assessment (LCA). According to this framework and by defining and measuring the numerical parameters representing the building environmental sustainability, it would be possible to compile regulations to estimate the optimum limit of these parameters and to keep them in a limited range. By doing so, it would be possible to provide for the current generation's needs without compromising the ability of the future generations to provide for their needs. This is an abstract meaning of sustainability itself.

Keywords: Construction industry, Sustainability, LCA, Sustainable development, Environment.

1. Introduction

After the Industrial Revolution, human knowledge made great deal of progress in software and hardware. This resulted in building production becoming one of the greatest industries in the world. Achieving new mathematical knowledge in structural calculation and invention of new materials, such as steel and concrete, provided the ability for man to create new construction systems and led to development of construction industry. In the 19 century, construction speed and novel structures were the most popular field in the construction industry, but in the following century, maintenance of the built structures became more important. There is just one important subject at the beginning of the 21st century that concerns the construction industry professional, demolition of buildings and putting an end to their existence.

In order to control the probable crisis of buildings demolition, a global movement started to increase environmental sustainability and reduce negative impacts of the construction systems on natural environment.

Production and maintenance of building is also as important. Thus, all the factors related to this issue have to be studied and assessed carefully. Destructive environmental impacts, expansion of CO₂ emission, unlimited use of renewable and non-renewable resources and importance of the future generations' needs are the most common topics of this global movement.

2. Crisis of Non-Sustainable Construction

As mentioned before and shown in the diagram below, it was found out that the expanding need of the world population for new buildings and accepting the development of construction industry as an undeniable fact is currently occurring.

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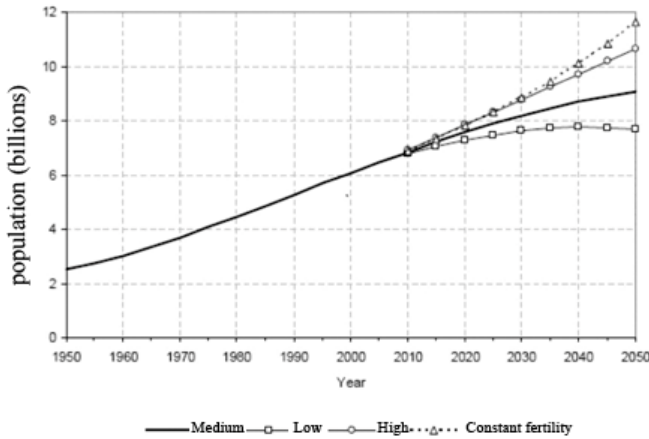


Fig. 1. Projection of world population. Source: Population division of the Department of economic and social affairs of the United Nations secretariat, 2005 [1]

According to the sustainable development's definitions, mentioned in the next pages, development of construction without controlling its undesired impacts on the environment, will increase fossil fuel use, CO₂ emission, environmental pollution and will bring about many other issues. As shown in the next diagram, every country in the world has to reduce its CO₂ emission to a certain level. Therefore, the construction industry, as one of the most polluting industries, is the direct target of the international programs. It's necessary to know that the construction industry uses 37% of all the produced energy and 30% of the water resources. At the same time, it creates 47% of the CO₂ [2]. Therefore the first meetings were held in 1990 to produce an appropriate tool for construction sustainability assessment [3-4].

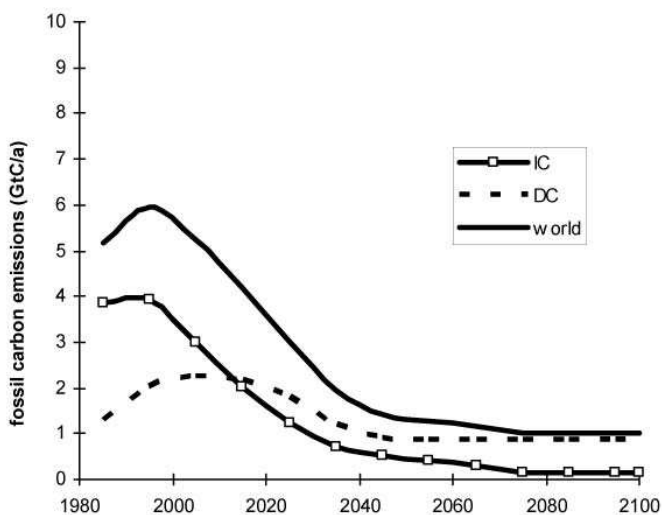


Fig. 2. Carbon emission scenarios based on 300 Gt global fossil carbon budget, split equally between industrialized countries (IC) and developing countries (DC). [1]

This movement was followed by several efforts to produce assessment tools like environmental preferences tool [5], green building assessment tool [6], LEED tool [7] and some other tools. Therefore, it could be understood

that no one doubts the necessity of environmental sustainability assessment for buildings. Most developed countries have special programs to control the destructive effects of the construction industry by measuring their environmental sustainability.

Iran is now trying to cross the necessary path to becoming a developed country. Attention to sustainability is one of the accelerating factors in a country's development. It causes higher performance and more economic growth. Because of the rapid growth of Iran's population, especially in the last two decades, and by glancing at the age proportion in the Iranian society's population pyramid, it's easy to anticipate an expanding need for construction, particularly in the residential sector. Low performance of the current common construction systems in Iran causes very low environmental, economic and social sustainability in the industry. It seems that continuing the current situation in construction will result in facing serious problems in the next 50 years. Although this crisis will accrue in all phases of construction, such as production, maintenance and demolition, the most destructive and critical phase is the last phase. Problems made by demolition wastes are the main part of the crisis. To have a better and more understandable view of the future crisis, an example model is given.

With the construction method used in Tehran, the buildings' life-time is about 50 years. Thus, after five decades, majority of the buildings in this city are up for demolition. Management of this large-scale demolition's waste will create a big problem. Although, this serious problem will be faced gradually in the years to come; nevertheless, it will appear suddenly. Previously similar crisis happened in some other industries in vehicle and computer industries and put many countries with no preventive programs in serious trouble. However, most of the developed countries dealt with this crisis successfully suffering minimum costs, because their prevention methods and strategies had been thought of in advance. With such experiences in other industries, it seems to be necessary to study the destructive environmental effects of construction systems in all phases of a structure's life, such as production, maintenance and demolition. Furthermore, it is needed to make effective decisions to control these disadvantages and guide the construction industry to have the maximum amount of sustainability.

3. Sustainability

3.1. Sustainable Development

Sustainable development is a new subject in research and scientific societies. The evidence shows a growing inclination toward studying this field in recent decades. One of the first studies in this field was in 1972 in the United Nations. Its result was published in Agenda 21 in 1992. These considerations were accomplished in the United Nations' conference in Rio de Janeiro and were developed by several national and international conferences and seminars. The main defined goal of these efforts was preservation of the natural environment for the

future generations. It was followed by the sustainable development theory [8]. A few of the available definitions for sustainable development are brought in the following paragraphs.

As defined in SAGE seminar, sustainable development is a result of providing human needs using technological, social and economic means simultaneously and progressing despite of the natural resources preservation [9]. Another definition given by the British sustainable development supporting society calls sustainable development as a process in which people can grow their potentials and increase support resources [10]. Sustainable development is described as a multiple subject concerning the natural environment, industry, economy, technology, politics and the media [11].

DETR definition calls sustainable development a subject that can guarantee a better life style for all people now and in the future. This goal could be achieved by using these tools [12]:

- Social progress which recognizes the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

Another famous definition is given by the World Committee of Environment and Development (WCED) in 1983 for the first time. It defines the sustainable development as a kind of development that meets the needs of the present generation without compromising the ability of the future generations to meet their own needs [11].

All given definitions have the same view, being that sustainable development is a multidisciplinary subject concerned with many fields, but the most important fields are social, economic and environmental sustainability. From this point of view, sustainable development is made up of three factors and when it's told that sustainable development happened it means that sustainability is achieved in three fields of society, economy and environment at the same time [13].

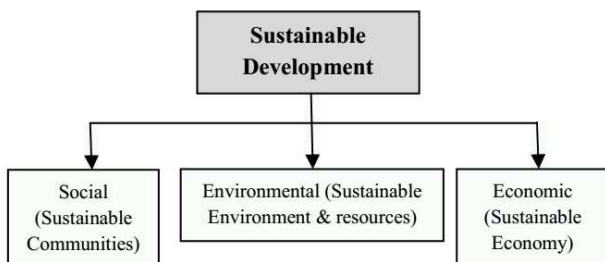


Fig. 3. Three themes of sustainable development [14]

3.2. Sustainable Construction

encouraging scientific discussion about sustainability, this topic entered construction industry, gradually. Sustainable construction is a kind of building production with responsible management with regard to the environmental rules and use of resources by the highest

possible performance [15]. In other words sustainable development is a specific approach of sustainability concerned with the construction industry. Also, construction industry is complex and consists of several phases like production, development, planning, construction and maintenance of the built environment. Therefore, sustainable construction can be described as a branch of sustainable development that contains financial and physical planning, designing, organizing, material selection, recycling and minimizing demolition waste [16].

As mentioned before, there are three fields in sustainability of development. It's also possible to study these three fields for construction sustainability. So, each field needs precise research and could be analyzed in different phases of a building's lifetime using technical and structural approaches in major and minor scale. Then, results of these studies could be compared with each other. Comparison of these results could found in the following pages.

3.3. Life Cycle Sustainability Assessment

The first step in composing a sustainable construction system is to change the design process in a way that sustainability principles could be addressed at the start point of the process. In order to achieve a sustainable design, creative methods are necessary to solve the technical problems. Successful methods are only those that emit less pollution with lower cost, conserve more energy and natural resource and also increase the health and satisfaction rate in the built space. Like any other problem, solving this one needs to be divided into smaller problems. Thus, a construction system has to be broken down into its components and a proper strategy should be found for each of the minor problems. By optimizing these minor elements, the whole system would get optimized. Main parts of a construction system can be described as [17]:

- Pre-use phase
- Use phase
- After use phase

As shown in Fig. 4, life cycle can be studied according to different construction using different approaches.

Building sustainability can be studied using environmental, economic, technologic and social-cultural approaches in different levels for all the phases of a building's life time. Therefore, we have a very complicated problem with several dimensions in a 3d diagram and several parameters can be defined through intersection nodes.

Optimizing any of these parameters can be a positive point in increasing the entire system's environmental sustainability. All these complications can be overcome by subdividing each point to smaller fields and starting optimization from these minor points.

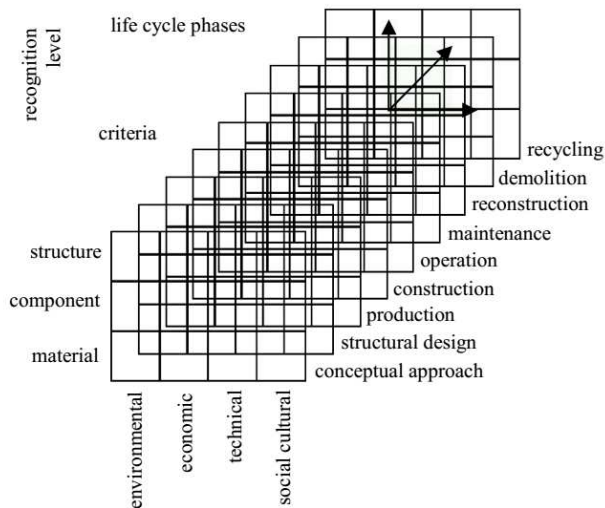


Fig. 4. Several study point in construction industry according to recognition level, life cycle phase and criteria [18]

This study is restricted to the construction material using the environmental approach in the entire life cycle of the phases.

3.4. Life Cycle Assessment (LCA)

There are many methods available for assessing the environmental impacts of materials and components within the building sector. While adequate to an extent for a particular purpose, they have disadvantages. LCA is a methodology for evaluating the environmental loads of processes and products during their whole life-cycle [15]. The assessment includes the entire life-cycle of a product, process, or system encompassing the extraction and processing of raw materials; manufacturing, transportation and distribution; use, reuse, maintenance, recycling and final disposal [16]. LCA has become a widely used methodology, because of its integrated way of treating the framework, impact assessment and data quality [21].

Following a product in all its life phases became popular in recent years, in order to assess and develop man made products, especially the industrial ones. The year 1997 can be mentioned as the start point. In 1997, the International Standardization Organization (ISO) published a new standard for environmental management of the industrial products. So, it was the first set of principles and frameworks to control the destructive environmental effects of the industrial products. Using this approach, several effective factors like energy, cost, water usage, labor amount, CO₂ emission and so forth could be considered ranging from excavation of the raw materials and production to the end of a product's lifetime, at which, it would be recycled or demolished. Combination of all these results shows the performance and the environmental efficiency of a product. Building environmental sustainability assessment needs tools that can evaluate a building in its life cycle. LCA offers a method with this capability [22].

LCA methodology is based on ISO 14040 and consists of four distinct analytical steps: defining the goal and

scope, creating the life-cycle inventory, assessing the impact and finally interpreting the results [18]. Employed to its full, LCA examines environmental inputs and outputs related to a product or service life-cycle from cradle to grave, i.e., from raw material extraction, through manufacture, usage phase, reprocessing where needed, to final disposal.

ISO 14040 defines LCA as: —A technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases. LCA is often employed as an analytical decision support tool. [19]. Historically it has found popular use comparing established ways of making and processing materials, for example comparing recycling with incineration as a waste management option [25].

Its necessary to pass specified steps to do life cycle assessment. They can be divided to four steps as mentioned in the table below:

Table 1 ISO 14040 format [26]

LCA Phase	Primary Activities
Goal & Scope Definition	Life Cycle Definition
	Functional Unit Definition
	System Boundary Definition
	Data Quality Determination
Inventory Analysis	Data Collection
	Quantification of inputs/outputs
Impact Assessment	Classification
	Characterization
	Weighting
Interpretation	Reporting
	Critical View

Considering about twenty five researches done between 2000 and 2007 in building assessment by LCA shows two different approaches in life cycle composition. About 60% of them done by Building Material and Components Composition (BMCC) and other 40% by Whole Process of Construction (WPC). These two approaches are compared in below:

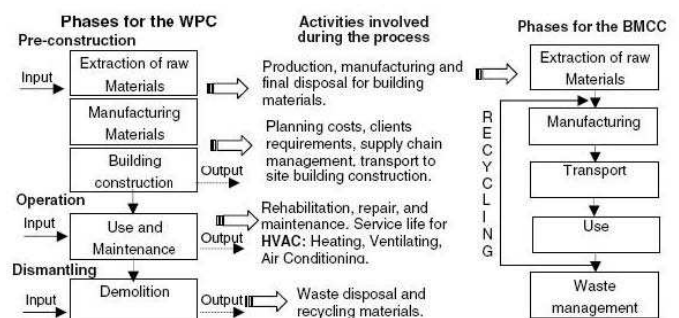


Fig. 5. Schematic representation of the building life cycle [27]

4. Strategies and Standards for Sustainable Construction

As mentioned before, first construction standard was published in 1997 by ISO. All known standards for building environmental sustainability were compiled after this year. Related standards by ISO are as follow:

- ISO 14040: Main principles for environmental standardization
- ISO 14041: Target compliment and component analysis
- ISO 14042: Environmental effects assessment
- ISO 14043: Life cycle assessment

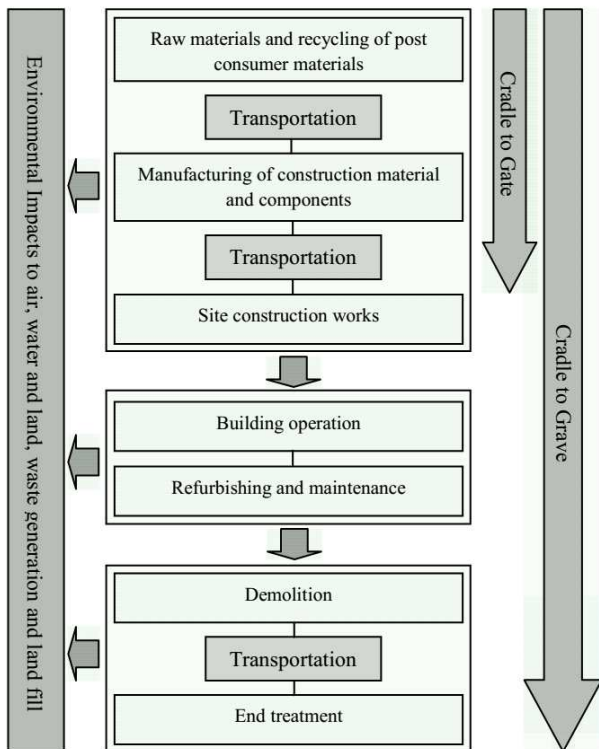


Fig. 6. Medium detailed flow diagram of a building/construction [28]

Several international standards show importance of the construction industry's environmental effects. However, in the first step, it seems necessary to find out what the specifications of a confirmed building by ISO standards are? And how could a building achieve them? The environmental friendly building or green building is a complex of strategic considerations in placement, design and construction that reduces the destructive effects of a building as much as possible [29]. Suitable design approach is needed to create these strategies. Therefore, all the resources such as materials, fuel, labor and so on must be considered in an architecture design to result in a sustainable construction. It seems that construction of a green building needs creative solutions for many paradoxes in the decision making phase of a design process. So, any decision in the design process has direct or indirect short-term and long-term environmental effects.

All the tools try to help their users to choose better and

more appropriate materials and design methods.

Due to the importance of the construction effects on environment, main specifications of a sustainable building that a regular building misses are follows [15]:

- Reduction of the embodied energy and resource depletion
- Minimization of the external pollution and the environmental damage
- Minimization of the internal pollution and damage to the health

Respecting these principles causes positive effects on the environmental health, resource conservation and the natural environment. A green building has some extra specifications other than those mentioned for a regular building, such as the cost, function, stability and the aesthetic. A few of them are as follows:

- Reduction of human exposure to noxious materials
- Conservation of non-renewable energy and scarce materials
- Minimization of the life cycle's ecological impact on energy and the material used
- Use of renewable energy and materials that are sustainably harvested
- Protecting and restoring the local air, water, soil, flora and the fauna
- Supporting the pedestrians, bicycles, mass transit and the other alternatives to the fossil fuelled vehicles

Many countries started comprehensive researches to achieve this target and several recommendations and programs were compiled on how to do so. According to the Agenda 21, a program for sustainable construction was implemented in Britain. According to this program, sustainable construction is a complex of processes by which a useful industry achieves a built environment. The following is a list of the steps which should be taken:

- Enhance quality of life and offer customer satisfaction
- Offer flexibility and the potential to cater for user changes in the future
- Provide and support a desirable natural and social environment
- Maximize efficient use of the resources
- Make a profit

Including all these parameters leads to getting a sustainable building and by losing each item, some part of sustainability will be lost [30].

Practicable recommendations can help the professionals to develop these items. Restriction of the sustainability items to measurable limited parameters and compiling the measuring tools and methods can be a starting point to composing a list of appropriate recommendations. By assessing these sustainability parameters and superposing, the output diagrams of these parameters could be drawn during a building's life cycle using the ISO standard as a reliable pattern. Thus, in each phase of a building's life-cycle, deviation of this diagram from the ISO standard can be measured and be considered as the system's fault. Then it could be corrected.

If correction is not possible, then, that item will be substituted or omitted from the construction system to increase the building's environmental sustainability.

By utilizing this approach, a system can find effective parameters

in the environmental sustainability and measure and correct them to create a new generation of construction systems with a higher rate of environmental sustainability.

4. 1. Effective Recommendations to Increase Environmental Sustainability of Construction Systems

A framework can be drawn for sustainable construction. Respecting the primary rules of this framework would result in [31]:

- Minimization of resources consumption
- Maximum of resources reuse
- Use renewable and recyclable resources
- Protect the natural environment
- Create a healthy and non-toxic environment
- pursue quality in creating the built environment

Sustainability of a building is not only restricted to the construction system but also design the process has a direct and an undeniable effect on its sustainability. Five main rules to achieve a sustainable design are as follows [32]:

- Healthy interior environment
- Energy efficiency
- Ecologically benign materials
- Environmental form
- Good design

In addition, more effective rules can be compiled to achieve sustainable construction. Following titles are main subjects for future researches in construction sustainability:

- Reuse old buildings
- Recycle waste materials
- Use salvaged materials
- If one must build new, check how much energy was used to produce the materials
- Consider low energy design
- Design buildings that are cheap to run
- Design building that will be cherished to increase the chance of reuse
- Design for flexible buildings
- Designing and constructing while keeping health and safety in mind

5. Parametric Approach

5.1. Environmental sustainability assessment tools

In recent decades, several assessment tools were invented to calculate the relationship between the construction materials and their environmental effects.

Some of the most important databases and tools for life-cycle assessment in different countries are arranged in the table below:

Table 2 Some databases and tools of life-cycle assessment of WCP and BMCC [28]

Database	Country	Function	Level	Software
Athena	Canada	Database +Tool	whole building design decision	Eco Calculator
Bath Data	UK	Database	product comparison	No
BEE	Finland	Tool	whole building design decision	BEE 1.0
BEES	USA	Tool	whole building design decision	BEES
BRE	UK	Database +Tool	whole building design decision	No
Boustead	UK	Database +Tool	product comparison	Yes
DBRI	Denmark	Database		No
Ecoinvent	SL	Database	product comparison	No
ECO-it	NL	Tool	whole building design decision	ECO-it
ECO Methods	France	Tool	whole building design decision	Under development
Eco- Quantum	NL	Tool	whole building design decision	Eco- Quantum
Envest	UK	Tool	whole building design decision	Envest
Gabi	Germany	Database +Tool	product comparison	Gabi 4
IO- database	Denmark	Database	product comparison	No
IVAM	NL	Database	product comparison	No
KCL- ECO	Finland	Tool	product comparison	KCL- ECO 4.1
LCAiT	Sweden	Tool	product comparison	LCAiT
LISA	Australia	Tool	whole building design decision	LISA
Optimize	Canada	Database +Tool	whole building design decision	Yes
PEMS	UK	Tool	product comparison	Web
SEDA	Australia	Tool	whole building assessment	SEDA
Simapro	NL	Database +Tool	product comparison	Simapro
Spin	Sweden	Database	product comparison	No

5.2. Environmental sustainability parametric assessment

As mentioned before, one of the most important steps

in the ISO framework for life cycle assessment is functional unit definition. All the previous recommendations are descriptive. It means that, in this paper, no functional unit is defined. Therefore, without

transforming the recommendations into measurable parameters, it would be impossible to calculate a building's environmental sustainability or even compare different buildings' sustainability rate with one another.

In order to compose a practical regulation that could be obtained by the professionals in construction industry in Iran, it's essential to define the parameters that are able to describe all the aspects of the environmental sustainability to enable the concerned organizations such as Iran's Building and Housing Research Center to compile assessment tools. All the assessment tools presented before have their own parameters and categorize buildings according to their parametric evaluation.

Investigation of all these sustainability assessment tools guides us to obtain a general view of sustainability parametric definition. One of the most complete sets of the environmental indicators is presented in a report called EIME (Environmental Improvement Made Easy) in 2009. Considering all the noticeable reports, researches and the manuals concerned with the environmental sustainability assessment, some of the most important, effective and measurable parameters for building's sustainability are briefly described: [33]

5.2.1. RMD (natural material depletion indicator)

The RMD indicator calculates the depletion of natural resources, taking into account the size of the resource reserve in ground and the consumption rate of today's economy. It is expressed in fraction of reserve disappearing per year (indeed the consumption rate is expressed as a quantity per year). Once the type reserve is identified, an index can be defined that will relate an inventory flow with the depletion of that resource. The proposed depletion indicator uses equivalency factors, i.e., each natural resource consumption recorded in the inventory is multiplied by the resource's weighting factor (or equivalency factor). As described in equation (1), the total depletion index is then compiled by adding the previous intermediate results for all inventory flows considered.

$$(1) Depletion = \sum_{Reserve} \text{equivalent factor}_{reserve} \times \text{inventory consumption}_{reserve}$$

Several methods can be used to produce the equivalency factors.

The indicator implemented in the EIMETM software is the index called "Ec(R*Y) - depletion of non renewable resources".

The overall result of resources depletion is calculated as follows:

$$RMD = \sum_{Reserve} \left(\frac{1}{reserve_{res} \times years_{reserve}} \times \text{inventory consumption}_{reserve} \right)$$

RMD indicator is expressed in the fraction of the reserve disappearing per year.

5.2.2. ED (energy depletion)

ED indicator account for energy consumption (or use), either derived of the combustion of fuels (fossil or not) or from other sources (hydroelectricity, tidal, solar, wind). Nuclear electricity is included in energy from uranium fuel. The indicator also considers the latent energy in materials (which is produced during the combustion of the material, typically at the end of life).

In order to be able to distinguished, Renewable energy and non renewable energy amounts, two different flows are integrated in the indicator calculation: It is expressed in MJ.

This indicator also is described in other sources as GER as Gross Energy Requirement in some other researches.

5.2.3. WD (water depletion indicator)

WD indicator is representing the water consumption during the product whole life cycle, ie the sum of consumption from any kind of water source or quality (drinkable, industrial, ...).

It is important to notice that water used for cooling or used in a closed loop process are not taken into account.

It is expressed in dm^3 .

5.2.4. GWP (global warming potential indicator)

The GWP indicator is representing the contribution to the global warming due to specific gas emissions in the atmosphere during the product life cycle. It is expressed in grams of CO2 equivalent. It means that Carbon dioxide is assigned a GWP of 1, while the GWP of other gases is expressed relative to the GWP of carbon dioxide from fossil carbon sources.

This indicator considers the potential direct effects on the Greenhouse Effect of the emission of 64 'greenhouse' gases over 100 years. The overall result of emission of these gases on the GWP is calculated as follows:

$$GWP = \sum GWP_i \times m_i$$

where, for a greenhouse gas 'i':

- m_i is the mass of the gas emissions (in g),
- GWP_i is its Global Warming Potential.

The GWP is expressed in gram CO2 equivalent.

The GWP_i (Global Warming Potential of the gas 'i') is defined as the ratio of the time integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas:

$$GWP = \left(\int_0^T ai \cdot Ci(t) \cdot dt \right) / \left(\int_0^T aCO_2 \cdot CCO_2(t) \cdot dt \right)$$

Where, for a greenhouse gas 'i':

- ai : heat radiation adsorption following the increase of concentration of gas 'i'.

- C_i(t)**: remaining concentration of gas 'i' in atmosphere at 't' time.
- T**: integration gap year.

5.2.5. ODP (stratospheric ozone depletion potential indicator)

The OD indicator is representing the contribution to the depletion of the stratospheric ozone layer by the emission of specific gases. It is expressed in grams of CFC-11 Equivalent.

This indicator considers the direct effect on stratospheric ozone depletion of the emission of 22 ozone depleting gases.

The overall result of emission of these gases on stratospheric ozone depletion (OD) is calculated as follows:

$$ODP = \sum ODP_i \times m_i$$

Where, for an ozone depleting gas *i*:

- m_i** is the mass of the gas released (in g),
- ODP_i** is its Ozone Depletion Potential.

The Ozone Depletion indicator is expressed in gram of CFC-11 equivalent.

The ODP_i (Ozone Depletion Potential of the gas 'i') is defined as the ratio between ozone breakdown in the equilibrium state due to annual emissions (in kg yr⁻¹) of a quantity of gas *i* released into the atmosphere, and the breakdown of stratospheric ozone in the equilibrium state due to an equal quantity of CFC 11, which is used as a reference.

5.2.6. AT, WT (air and water toxicity indicator)

The AT indicator is representing the air toxicity in a human environment, taking into account the usually accepted concentrations tolerated for several gases and the quantity released. The given indication corresponds to the air volume necessary to dilute « contaminated air ».

The WT indicator is representing the water toxicity. This indicator takes into consideration the usually accepted concentrations tolerated for several substances and the quantity released. The given indication corresponds to the air volume necessary to dilute « contaminated water ».

The overall result is calculated as follows:

$$AT = \sum \left(\frac{\text{inventory air emission}_i}{\text{Limit Value}_i} \right)$$

$$WT = \sum \left(\frac{\text{inventory water emission}_i}{\text{Limit Value}_i} \right)$$

The Limit Values are expressed in g/l, so that the AT and WT are expressed in volume (dm³ for WT and m³ for AT).

5.2.7. POC (photochemical ozone creation indicator)

The POC indicator calculates the potential creation of tropospheric ozone ("smog") by the release of specific gases which will become oxidants in the low atmosphere under the action of the solar radiation. It is expressed in grams of ethylene (C₂H₄) equivalent.

POCP based on three scenarios and 9 days; FRG-Ireland, France-Sweden and UK. The overall result of emission of these gases on the POC is calculated as follows:

$$POC = \sum POCP_i \times m_i$$

where, for a volatile organic compound gas 'i':

- **m_i** is the mass of the gas released (in g),
- **POCP_i** is its Photochemical Ozone Creation Potential.

POCP index is expressed in gram of ethylene (C₂H₄) equivalent.

The **POCP_i** (POCP of an emission *i*) is the ratio between the change in concentration due to a change in the emission of that VOC and the change in the ozone concentration due to a change in the emission of ethylene.

The POCP of a VOC is estimated as the quantity of ozone produced when one gram of this VOC is released.

5.2.8. AA (air acidification potential indicator)

The AA indicator presents the air acidification by gases released to the atmosphere. It is expressed in grams of H⁺, as if all gases were H⁺, using equivalency in their acidification potential.

This indicator considers the direct effect on air acidification of the emission of substances listed in Table of the appendix. The overall result of emission of the substances on the AA is calculated as follows:

$$AA = \sum \left(\frac{m_i}{AP_i} \right)$$

where, for an acidification substance *i*:

- m_i** is the mass of the substance released (in g),
- AP_i** is its Acidification Potential

The Air Acidification Indicator (AA) is expressed in gram of H⁺ equivalent.

An Acidification Potential (AP) of a substance is calculated on the basis of the number of H⁺ ions which can be produced per mole (given by the stoichiometry of the oxidation reaction). However, as emissions are specified in g rather than in moles, the latter quantity has to be divided by the molecular weight of the substance. APs are developed by analogy with the GWP.

5.2.9. WE (water eutrophication indicator)

WE indicator is representing the water eutrophication (enrichment in nutritive elements) of lakes and marine waters by the release of specific substances in the effluents. It is expressed in grams of PO₄³⁻, as if all substances were PO₄³⁻, using equivalency in their

nitrification potential.

The Eutrophication (water) index is an amended version of an index produced by CML. It has been introduced by Ecobilan as the CML oxygen depletion index does not seem to be an adequate index for terrestrial nitrification. The Eutrophication (water) index is restricted to water eutrophication. The flows included are the emissions of nutritive

compounds in water and COD. The overall result of emission of the substances on the WE is calculated as follows:

$$WE = \sum NP_i \times m_i$$

where, for the nutritive compound *i*:

- *mi* is the mass of the compound (in g),
- *NP_i* is the Nitrification Potential of the compound.

The Eutrophication Water Indicator is expressed in gram of phosphate equivalent.

Eutrophication is assessed through oxygen depletion. The Nitrification Potential (*Npi*) of the compound *i* is based on its potential contribution to the formation of the « Redfield » algae biomass (C106H263O110N16P). This contribution is translated into oxygen depletion taking into account the quantity of oxygen consumed when algae decomposes. The COD is already expressed as a quantity of consumed oxygen. All the nitrification potentials are normalized by the phosphate potential.

5.2.10. HWP (hazardous waste production indicator)

HWP Indicator calculates the quantity of hazardous waste produced for a given product. It is added to the flows of the LCA inventory which correspond to hazardous waste.

It is expressed in kg.

6. Life Cycle Sustainability Assessment Framework

Combination of ten parameters, mentioned above, covers most aspects of the sustainability. Assessment of these parameters is a scientific way to calculate sustainability as a non-parametric subject through dividing the subject into measurable parameters.

Brief description and calculation of these parameters has also been mentioned previously. The next step in assessment and improvement of the construction system's environmental sustainability is to measure any of these parameters from the beginning to the end of the building's life cycle. These criteria can be described as follows:

Total life cycle= (Pre-use + Operation + End life) Phases

Each phase can also be divided into smaller parts:

Pre-use phase= Excavation of raw material + Material process + Transport + Construction

It means that the pre-use phase of a building includes several parts and any of the sustainability parameters should be assessed in all of these sub phases. Furthermore,

the pre-use phase amount of any of the ten parameters is a result of all these steps put together.

The operation phase is the most investigated phase of a building's life cycle all around the world and Iran is not an exception. The 19th chapter of Iran's national building regulation is entirely about the assessment and control of the energy consumption of a building during its operation phase, design phase is included. Even, this phase is also restricted to the energy consumption which represents ED (Energy Depletion), which is also called GER (Gross Energy Requirement). So, the other nine parameters should be investigated, as well. Maintenance, repair, renovation and reconstruction should be measured as the sub phases of the operation phase.

The last phase of a building's life cycle includes some sub phases:

End life Phase= Demolition + Transport + Recycling

Restoration and Rehabilitation can be considered as another possible end life scenario for a building. In any case, this phase of a building's life cycle is as important and complicated as the previous ones and should be investigated and measured.

Following up and measuring the construction materials in all the phases of a building is possible, now. It is necessary to figure out the impact factor of any of the ten parameters in any of the phases and sub-phases and simultaneously estimate the upper limit, lower limit and the optimum amount of any of these parameters for each phase. On the other hand, giving useful recommendations to bring parameters into the defined range and improving environmental sustainability is necessary, too.

By using this approach, the limitations of the parameters can be composed as regulations that should be respected by all the professionals in the construction industry, from manufacturers of building materials to the constructors. Furthermore, issuing the construction permission certificate can depend on respecting all the recommended limits and preventing any construction taking place which is out of the defined environmental ranges.

Therefore, it is possible to have a complete, practical and multidisciplinary regulation for the assessment and improvement of the buildings' environmental sustainability during its life cycle. Also, emphasis on the construction materials or any other elements of a building is a must.

7. Conclusion

According to previous page it's easy to find out that in current decade, the most important subject related to construction industry is controlling environmental effects of a construction system. Prudent consumption of renewable and non-renewable resources to provide current generation needs without compromising future generations to provide their needs, resulted many researches in environmental performance of construction systems and optimizing them all around the world. Among many invented tools for sustainability assessment, LCA is the most popular with it's two approaches called BMCC and WPC. International standardization organization (ISO) also compiled some criterions to standardize construction

systems. With a glance at all these international efforts to improve environmental sustainability and despite of current low performance construction systems in our country, it is necessary to compile simple and practicable recommendations to reform current situation and in further steps more serious researches can be started to invent local tools to assess environmental sustainability of construction systems scientifically. Sustainability as a non-parametric subject can be described and measured by ten specific parameters called environmental indicators. These indicators can be mentioned as a result of all efforts toward assessment of environmental sustainability including databases, regulations and also software. These ten parameters could be calculated as indicator impact during all sub phases of a building life cycle from the beginning to the end.

$$II = \sum_{n=production}^{recycling} (\text{Indicator Amount}_n \times \text{Indicator Weight}_n)$$

II: Indicator Impact

These parameters could be calculated during all sub phases of a building life cycle from the beginning to the end and it should be mentioned that the indicator amount in all phases do not have same value so they should be calculated according to their weight and it should include all phases and sub phases of a building life cycle.

Indicator impact calculation only shows the level of environmental sustainability. To improve a building environmental sustainability, permitted amount of each indicator impact should be calculated and respected from the beginning of a building life cycle, even from design phase.

$$\text{Lower Limit} \leq \text{Indicator Impact} \leq \text{Upper Limit}$$

Respecting limitation of these parameters and optimum amount of them, it would be possible to compile new regulations and even new chapters of National Building Regulation for assessment and improvement of construction systems environmental sustainability by life cycle numerical parametric measurement approach that can result in a great amount of energy and national resource saving and preservation of natural environment.

References

- [1] Robert Lowe. Defining Absolute Environmental Limits for the Built Environment, 2006, pp.1-30.
- [2] Gian Andrea Blengini. Life cycle of buildings, demolition and recycling potential, Building and environment, 2009, Vol. 44, pp. 319-330.
- [3] BRE 1990 BREEAM – Building Research Establishment Environmental Assessment Method. Version 1/90, BRE 183, Watford: BRE.
- [4] Cole R. Changing context for environmental knowledge, Building Research & Information, 2004, No. 2, Vol. 32, pp. 91-109.
- [5] Anink D, Boonstra C. Handbook of Sustainable Building: An Environmental Preference Method for Choosing Materials in Construction and Renovation, London: James & James (Science Publishers), 1996.
- [6] Cole R, Larsson NK. GBC '98 and GBTool, Building Research & Information, 1999, Vol. 27, pp. 221-229.
- [7] USGBC 2003 Green Building Rating System For New Construction & Major Renovations (LEED-NC) Version 2.1 (revised edition), Washington DC: US Green Building Council.
- [8] Parkin S. Context and drivers for operationalizing sustainable development, Proceedings of ICE, 2000, Vol. 138, pp. 9–15.
- [9] Sage AP. Risk management for sustainable development, Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, 1998, Vol. 5, pp. 4815–4819.
- [10] Parkin S. Sustainable development : the concept and the practical challenge, Proceedings of ICE, Vol. 138, 2000, pp. 3–8.
- [11] Chaharbaghi K, Willis R. Study and practice of sustainable development, Engineering Management Journal, 1999, No. 1, Vol. 9, pp. 41–48.
- [12] Sustainable Development: What it is and what you can do, DETR Green Ministers Report, March 2000.
- [13] http://www.cbpp.org.uk/cbpp/themes/suscon/intro_1/htm, Introduction to sustainable construction.
- [14] Malik MA Khalfan, Sustainable Development and Sustainable Construction, 2002.
- [15] <http://www.arch.hk/research/BEER/sustain.htm>, Sustainable architecture and building design.
- [16] CA and Ding GKC. (Eds.). Sustainable practices in the built environment, Langston, Butterworth-Heinemann, Oxford, 2001.
- [17] Architecture: Is change required?, Building, Feb. 1995.
- [18] Doc. Ing. Petr Hájek, CSc, Czech Technical University in Prague, Complex Methods for Life Cycle Analysis (Lca) and Life Cycle Cost (Lcc) Assessments, Center of integrated design and infra structures, 2005, 1 p.
- [19] Sonnemann G, Castells F, Schuhmacher M. Integrated Life-Cycle and Risk Assessment for Industrial Processes, Lewis Publishers: Boca Raton, FL, USA, 2003.
- [20] Consoli F, Allen D, Boustead I, Fava J, Franklin W, Jensen A, Oude N, Parrish R, Perriman R, Postlethwaite D, Quay B, Seguin J, Vigon B. Guide Lines for Life-Cycle Assessment: A 'Code of Practice. Society of Environmental Toxicology and Chemistry SETAC: Pensacola, FL, USA, 1993.
- [21] Klöpffer W. The role of SETAC in the development of LCA, International Journal Life Cycle Assess, 2006, Vol. 11, pp. 116-122.
- [22] Alisa M, Heasman I. Concrete, No. 1, Vol. 34, 2000, pp. 26.
- [23] ISO 14040 Environmental Management Life Cycle Assessment Principles and Framework, International Standards Organization: Brussels, Belgium, 2006.
- [24] Fava JA, Consoli F, Dension R, Dickson K, Mohin T, Vigon B. A Conceptual Framework for Life-Cycle Impact Assessment; Society of Environmental Toxicology and Chemistry SETAC: Sandestin, FL, USA, 1993.
- [25] Selmes DG. Towards Sustainability: Direction for Life Cycle Assessment, PhD thesis, Heriot Watt University: Edinburgh, UK, 2005.
- [26] Chris W. Scheuer and Gregory A. Keoleian, Life Cycle Assessment Methods, U .S. Department Of Commerce, National Institute of Standards and Technology, September 2002, 14 p.
- [27] Oscar Ortiz, Sustainability in the construction industry, Construction and building materials, 2009, Vol. 23, pp. 30-35.

- [28] Mohamad M. Khasreen, Phillip FG. Banfill, Gillian F. Menzies. Life-Cycle Assessment and the Environmental Impact of Buildings: A Review, *Sustainability* 2009, pp. 674-685.
- [29] Emison GA. Civil engineers and future environmental policies, *Journal of Professional Issues in Engineering Education and Practice*, 2001, No. 3, Vol. 127, pp. 130-138.
- [30] Cook A. What is sustainable construction exactly?
- [31] Miyatake Y. Technology development and sustainable construction, *Journal of Management in Engineering*, 1996, No. 4, Vol. 12, pp. 23-27.
- [32] Fisher TA. *Principles of Environmental Architecture*, AIA, 1992.
- [33] Bureau veritas, EIME (Environmental Improvement Made Easy), *Life Cycle Analysis and Eco design software, Indicators manual*, 2009.