Assessment and improvement of construction systems environmental sustainability

(By numerical parametric measuring tools for constructional materials in life cycle phases)

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Abstract: Today, development of construction industry is an undeniable fact according to large expansion of population. New subjects such as sustainable development, environmental pollution, resources conservation, reduction of CO2 emission became as the most important research topics among scientific societies all around the world. In recent years, specially after 1997, new tools were invented to assess construction systems environmental sustainability. The same item in all of them is to improve environmental sustainability of construction systems. In Iran, no serious attention is paid to unpleasant environmental impacts and high rate of pollution resulted by construction systems. But in a near future it will create a great crisis, so it seems necessary to compile effective plans to measure and control environmental sustainability of different construction systems in our country. In this paper we try to study the most important and recent methods of sustainability assessment in last years and analysis them comparatively so we would be able to draw a framework to move common construction systems in Iran toward environmental sustainability so it would be possible to provide current generation needs without compromising ability of future generations to provide their needs that is an abstract meaning of sustainability itself.

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

1.Introduction

After industrial revolution, human knowledge made great progress in software and hardware, and building production became one of the greatest industries in the world. Achieving new mathematical knowledge in structural calculation and invention of new materials like steel and concrete provide ability of man to create new construction systems and caused development of construction industry. In 19th century, construction speed and novel structures were the most popular field in construction industry, but in the next century maintenance of built structures became more important. There is just one important subject at the beginning of the 21st century that concern construction industry professionals to itself and that is demolition of buildings and finishing the life of these industrial products. In order to control the probable crisis of buildings demolition, a global movement started to increase environmental sustainability and reduce negative impacts of construction systems on natural environment. Production and maintenance of building are also as important as it's demolition in this way and all these factors 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 future generations needs are the most common topics of this global movement.

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2.Crisis of non-sustainable construction

As mentioned before and shown in the below diagram, we can find out the expanding need of world population to new buildings and accept development of construction industry as an undeniable fact that is just happening at present.

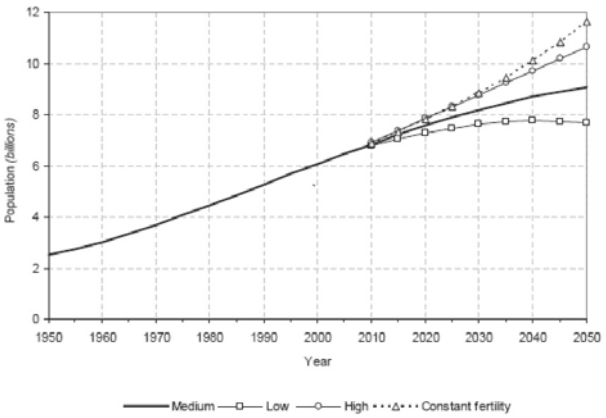

Figure1. Projection of world population. Source: Population division of the Department of economic and social affairs of the United Nations secretariat, 2005

According to sustainable development definitions that are brought in next pages, development of construction without controlling it's undesired impacts on environment, will increase fossil fuel use, CO2 emission, environmental pollution and many other disadvantages. As shown in the next diagram, every countries in the world has to reduce it's CO2 emission to a certain limit. Therefore, construction industry as one of the most polluting industries is direct target of international programs. It's necessary to know that construction industry uses 37% of all produced energies and 30% of water resources and also creates 47% of CO2 [1]. Therefore the first meetings were held in 1990 to produce appropriate tool for construction sustainability assessment [2-3].

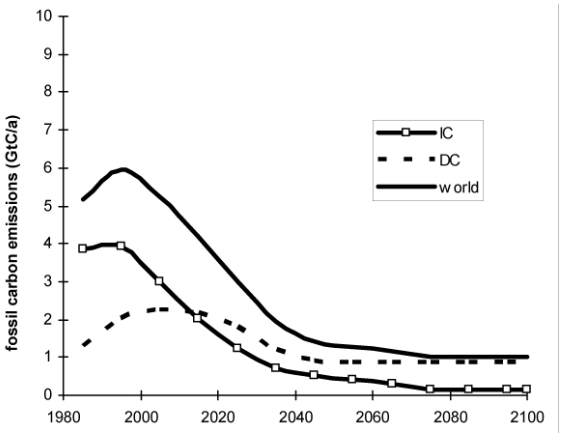

Figure 2. Carbon emission scenarios based on 300 Gt global fossil carbon budget, split equally between industrialized countries (IC) and developing countries (DC).

This movement was followed by several efforts to produce assessment tool like environmental preferences tool [4], green building assessment tool [5], LEED tool [6] and some other tools. So we can understand that no one has doubt in necessity of environmental sustainability assessment for buildings. Most developed countries have special programs to control destructive effects of construction industry by measuring their environmental sustainability. [44]

Our country is now trying to pass necessary steps to become a developed country. Attention to sustainability is one of accelerating factors in a country development that causes more performance and so more economic growth. Because of rapid growth of Iran population specially in last two decades and with a glance at age proportion in Iranian society population pyramid, its easy to anticipate an expanding need to construction and significantly residential construction. Low performance of current common construction systems in Iran causes very low environmental, economic and social sustainability in this industry. It seems that continuing current situation in construction will make serious problems in next 50 years. Although this crisis will accure in all phases of construction like production, maintenance and demolition, but 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 understandable view of the future crisis an example model is given.

Let's suppose that all buildings in Tehran are constructed in current year and there is no older building, according to about 50 years average lifetime considered for most buildings with current construction methods in Tehran, in the best situation all of them will have to be demolished after five decades. Management of this huge amount of demolition waste will create a big problem. Although, this serious problem will be produced gradually during these years with no sign but it will appear in future suddenly. Previously similar crisis happened in some other industries like vehicle and computer industries and put many countries with no preventing programs into serious trouble but most developed countries passed this crisis successfully with minimum costs because of their preventing and solving strategies had been made before. With such experiences in other industries, now it seems necessary to study destructive environmental effects of construction systems in all life phases such as production, maintenance and demolition and make effective decisions to control these disadvantages in the minimum possible rate and guide construction industry to the maximum amount of sustainability.

3. Sustainability

3.1. Sustainable development

Sustainable development is a new subject in research and scientific societies and evidences show first wishes to study this field in recent decades. One of the first considerations in this field was in 1972 in the United Nations and it's result was published in Agenda21. In 1992 this considerations were accomplished in United Nations conference in Rio de Janeiro and were developed by several national and international conferences and seminars. Main defined goal of these efforts was preservation of natural environment for future generations and further followed by sustainable development theory [7]. Some of several available definitions for sustainable development are brought in next paragraphs.

As defined in SAGE seminar, sustainable development is a result of providing human needs by technologic, social and economic simultaneously progress despite of natural resources preservation [8]. Another definition given by British sustainable development supporting society calls sustainable development as a process in which people can grow their potentials and increase their life quality and also take sufficient care of natural support resources [9]. Sustainable development is described as a multiple subject concern with natural environment, industry, economy, technology, politics and media [10].

DERT definition calls sustainable development a subject that can quarantining a better life style for all people in current and future generations. This goal could be achieved by using these tools [11] :

- 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 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 future generations to meet their own needs [10].
All given definitions have a same view 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 tree factors and when it's told that sustainable development happened it means that sustainability is achieved in triple filed of society, economy and environment in a same time [12].

Figure 3. Three themes of sustainable development

3.2. Sustainable construction

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

possible performance [13]. In other words sustainable development is a specific approach of sustainability concerned with construction industry. Also construction industry is a complex 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 [14].
As mentioned before, there are three fields in sustainability of development. It's also possible to study these triple fields for construction sustainability. So, each field needs precise researches and could be analyzed in different phases of a building lifetime by technical and structural approaches in major and minor scale. Then results of these studies could be compared with each other that follow in next pages.

3.3. Life cycle sustainability assessment

The first step in composing a sustainable construction system is to change design process in a way that sustainability principles could be mentioned in the start point of the process. In order to achieve sustainable design, creative methods in solving technical problems are necessary. Successful methods are only those that emit less pollution with lower cost, conserve more energy and natural resource and also increase health and satisfaction rate in built space. Like any other problem, solving this problem also needs to be divided to smaller problems. So we have to break down a construction system to it's components and find proper strategy for each minor problem. By optimizing these minor elements, whole system would get optimized. Main parts of a construction system can be described as below [15] :

- Building envelope
- Air conditioning system
- Security and fire control
- Lighting system
- Power and communication system
- Integration of building and services

Therefore sustainable design is a result of integrity of architecture with structure, mechanical and electrical engineering. So beside aesthetic features like proportion, light, color, form and material, long term topics such as environment, economy and society are noticeably important to create sustainable architecture.
Building envelope can be selected as the most measurable part of a construction system numerically. It include several elements like foundation, structure, floor slabs, outside walls , curtain walls and all openings in walls. Next picture shows a better view. This tripod has three axis which are for life cycle of a building, level of investigation and study approach. Several parameters are defined on each axis. As it shows, a building sustainability can be studied by environmental, economic, technologic and social-cultural approaches in different levels for all phases of a building life time. Therefore we have a very complicated problem with several dimensions in a 3d diagram. Optimizing each intersection of these axes can be a positive point to increase whole system environmental sustainability. All these complicities can be overcome by subdividing each point to smaller fields and start optimization from these minor points.

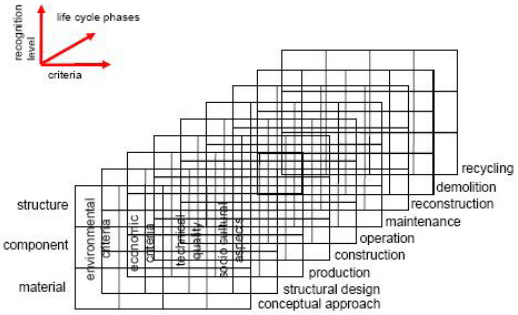

Figure 4. Several study point in construction industry according to recognition level, life cycle phase and criteria

Study extents in this paper is restricted to construction material by environmental approach in all life cycle of phases.

3.4. Environmental sustainability assessment tools

In recent decades, several assessing tools were invented to calculate relationship of construction materials and their environmental effects. All tools try to help their users to choose better and more appropriate materials and design methods. There are three major research foundations that are actively investigating in this field.

- Building Research Establishment (BRE)
- Building for Environmental and Economic Sustainability (BEES)
- Life Cycle Explorer

Each one of these organizations has it's own tools. Some of their most important methods are as below:

- Building Research Establishment Environmental Assessment Method (BREEAM)

This is a tool that helps all users such as owners, designers and constructors to figure out environmental sustainability rate of their construction method and optimize it [16].

- Echo homes tool

This tool can evaluate environmental performance of a residential building and categorize them in a range from pass to excellent. In fact this tool can be supposed as residential version of BREEAM. This is an understandable tool with ability of assessing new and renovated buildings. Most of it's recommendations are related to designing phase therefore this approach impose less cost than other tools that focus on next phases. Many parameters are included such as energy, transportation, water, environment, land use, pollution, health and materials [28].

- Life Cycle Assessment (LCA)

Following a product in all it's life phases became popular in recent years, to assess and develop man made products specially industrial ones. We can mention 1997 as the start point. In 1997, International Standardization Organization (ISO) published a new standard for environmental management of industrial products. So it was the first principles and frameworks to control destructive environmental effects of industrial products. By this approach several effective factors like energy, cost, water usage, labor amount, CO2 emission and so on should be mentioned from excavation of raw materials and production to the end of a product lifetime that it would be recycled or demolished. Combination of all these results shows performance and environmental efficiency of a product. Building environmental sustainability assessment needs tools that can evaluate a building in it's life cycle. LCA brings a method with this capability [17].

Its necessary to pass specified steps to do life cycle assessment. They can be divided to four steps as below chart:

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 Review

Figure 5. ISO 14040 format

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 chart:

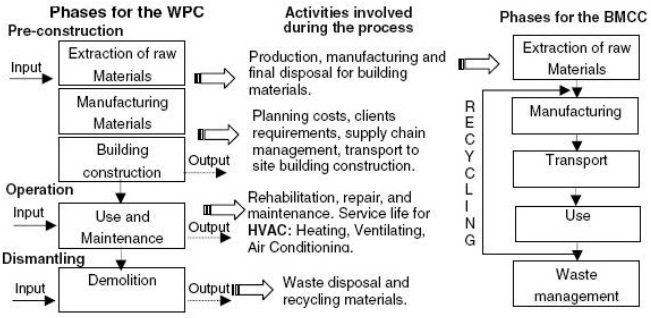

Figure 6. Schematic representation of the building life cycle

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

Several international standards show environmental effects of construction industry importance. But in the first step it seems necessary to find out that what are specifications of a confirmed building by ISO standards? And how could a building achieve them?

Environmental friendly building or green building is a complex of strategic considerations in placement, design and construction that reduce destructive effects of a building as much as possible [20]. Suitable design approach is needed to create these strategies. Therefore, all resources such as materials, fuel, labor and so on must be mentioned in architecture design to make sustainable construction. Is seems that construction of a green building need creative solutions for many paradoxes in decision making phase of design process. So any decision in design process has direct or indirect short-term and long-term environmental effects.

According to importance of construction effects on environment, main specifications of a sustainable building that a regular building misses are as below [13]:

- Reducing embodied energy and resource depletion

- Reducing energy in use
- Minimizing external pollution and environmental damage
- Minimizing internal pollution and damage to health

Respecting these principles causes positive effects on environmental health, resource conservation and natural environment. A green building has some extra specifications beside those mentioned in regular building like cost, function, stability and aesthetic like:

- Reduction of human exposure to noxious materials
- Conservation of non-renewable energy and scare materials
- Minimization of life cycle ecological impact of energy and material used
- Use of renewable energy and materials that are sustainably harvested
- Protect and restore local air, water, soil, flora and fauna
- Support pedestrian, bicycles, mass transit and other alternatives to fusil fuelled vehicles

Many countries started spread researches to achieve this target and several recommendations and programs were compiled so. According to Agenda21, a program for sustainable construction was performed in Britain. According to this program, sustainable construction is a complex of processes by which a useful industry results a built environment:

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

Including all these parameters causes a sustainable building and by losing each item, some part of sustainability will be lost [24].
Practicable recommendations can help professionals to develop these items. Restriction of sustainability items to measurable limited parameters and compiling measuring tools and methods can be a start point to compose appropriate recommendations. In this way assessing these sustainability parameters and superposing output diagrams of this parameters could be drawn during a building life cycle according to ISO standard as a reliable pattern. So in each phase of a building life, deviation of this diagram with ISO standard can be measured as system fault and been corrected [36].

In the next step, positives and negative points can be recognized and corrected as much as possible. If correction is not possible that item will be substituted or omitted from the construction system to increase building environmental sustainability.
By this approach, a system can find effective parameters in environmental sustainability and measure and correct them to create a new generation of construction systems with higher rate of environmental sustainability.

5. Effective recommendations to increase environmental sustainability of construction systems:

A framework can be drawn for sustainable construction. Respecting primary rules of this framework would result [22]:

- 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 districted to construction system and also design process has direct and undeniable effect on sustainability. Five main rules to achieve sustainable design are as below [23]:

- 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
- Design and construct with health and safety

6. 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.

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