CONTRIBUTION OF THE PRINCIPLES OF LEAN CONSTRUCTION TO MEET THE CHALLENGES OF SUSTAINABLE DEVELOPMENT

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ABSTRACT

This paper suggests the challenges of sustainable development to be considered in the life cycle process of buildings. Sustainable development concepts are presented featuring social, ecological, cultural and environmental facets. Examples of sustainable construction practices from different countries are described. The potential and profitability of lean principles to promote sustainable construction is raised for discussion. As an example of related development, a requirements framework, is presented.

KEYWORDS

Life cycle process of buildings, requirements management, sustainable design, sustainable construction.

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CHALLENGES OF SUSTAINABLE DEVELOPMENT

BUILDINGS AND THE ENVIRONMENT (= WHY?)

The quest towards sustainable development in our societies puts the spotlight on the built environment and the construction industry. Construction, buildings and infrastructure are the main consumers of resources: materials and energy. In the European Union, buildings require more than 40 % of the total energy consumption and the construction sector is estimated to generate approximately 40 % of the man-made waste (Sjöström 1998). Environmental burdens caused by construction can be minimized and construction technology can be used to remedy the environment. Sustainable construction is the response of the building sector to the challenge of sustainable development (Figure 1).

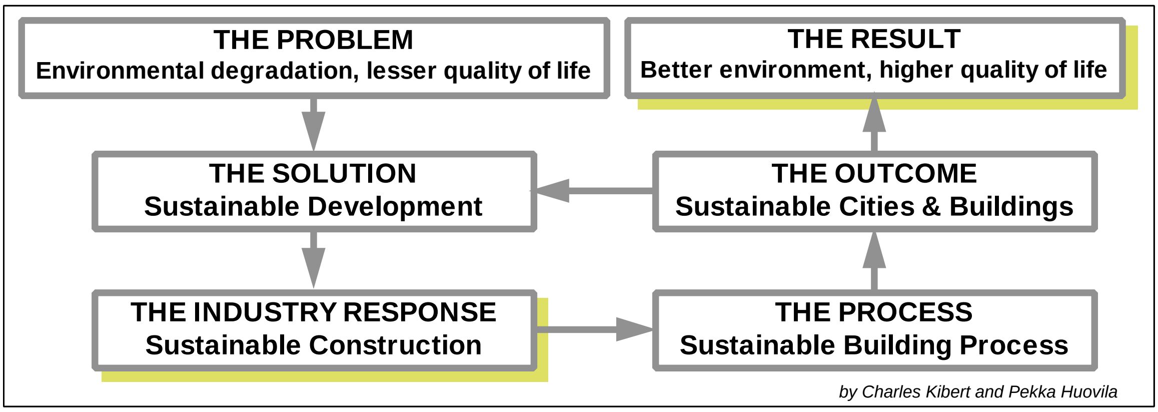

Figure 1: A simplified road map for sustainable construction (Bourdeau et al. 1998)

SUSTAINABLE DEVELOPMENT DEFINITIONS AND CONCEPTS (= WHAT?)

Sustainable development has several definitions, such as:

- "*development that meets the needs of the present without compromising that ability of future generations to meet their own needs*" [the Brundtland Report, WCED, 1987]
- "*improving the quality of human life while living within the carrying capacity of supporting ecosystems*" [Caring for the Earth, IUCN/UNEP, 1991]
- "*development that delivers basic environmental, social and economic services to all residences of a community without threatening the viability of natural, built and social systems upon which the delivery of those systems depends*" [International Council for local Environmental Initiatives, 1996]
- "*determined to promote economic and social progress for their peoples, taking into account the principle of sustainable development and within the context of the accomplishment of the international market and of reinforced cohesion and environmental protection, and to implement policies ensuring that advances in economic integration are accompanied by parallel progress in other fields*" [Amsterdam Treaty, 1997]

- "*it is about ensuring a better quality of life for everyone, now and for generations to come*" [Consultation paper[3] on a UK strategy for sustainable construction, 1998].

Sustainable objectives often emphasize environmental burdens. However, environmental issues often cannot be tackled if the problem of poverty remains unsolved. Hart (1997) separates different economic spheres (Table 1) when identifying major challenges to sustainability.

Table 1: Major challenges to sustainability (Hart 1997)

	Pollution	***Depletion***	***Poverty***
DEVELOPED ECONOMIES	▷ greenhouse gases ▷ use of toxic materials ▷ contaminated sites	▷ scarcity of materials ▷ insufficient reuse and recycling	▷ urban and minority unemployment
EMERGING ECONOMIES	▷ industrial emissions ▷ contaminated water ▷ lack of sewage treatment	▷ overexploitation of renewable resources ▷ overuse of water for irrigation	▷ migration to cities ▷ lack of skilled workers ▷ income inequality
SURVIVAL ECONOMIES	▷ dung and wood burning ▷ lack of sanitation ▷ ecosystem destruction due to development	▷ deforestation ▷ overgrazing ▷ soil loss	▷ population growth ▷ low status of women ▷ dislocation

While traditional design and construction focuses on cost, performance and quality objectives, sustainable design and construction adds to these criteria minimization of resource depletion, minimization of environmental degradation, and creating a healthy built environment (Kibert 1994). The shift to sustainability can be seen as a new paradigm (Vanegas et al. 1996) where sustainable objectives are within the building design and construction industry considered for decision making at all stages of the life cycle of the facility. Figure 2 outlines the evolution and challenges of the sustainable construction concept in a global context.

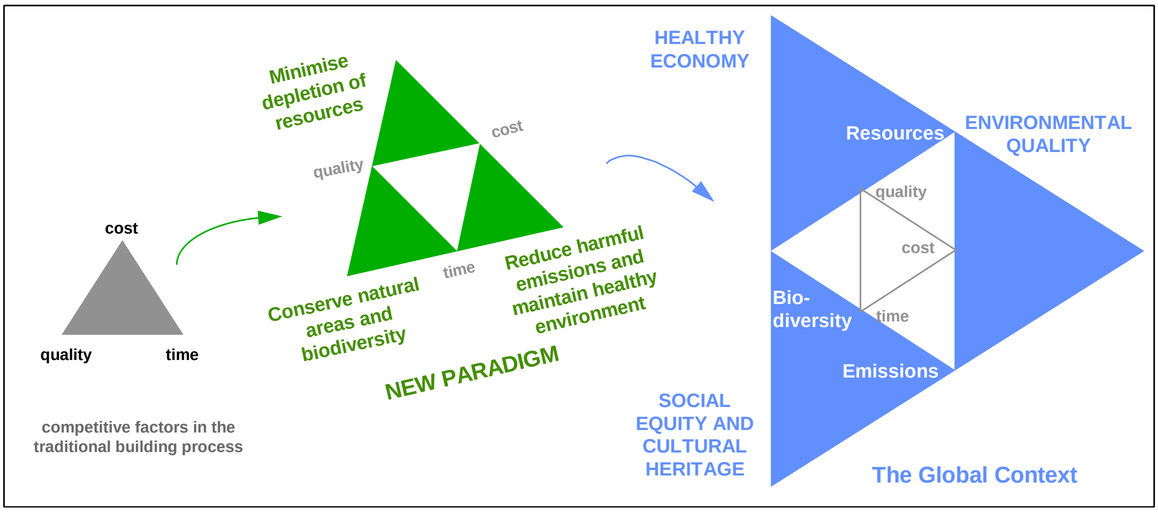

Figure 2: Challenges of sustainable construction in a global context

[3] http://www.environment.detr.gov.uk/sustainable/consult1/index.htm

SUSTAINABLE CONSTRUCTION IMPLEMENTATION (= HOW?)

Current sustainable construction practices are widely different depending on how the concept of sustainable construction is developed in various countries (Bourdeau et al. 1998). The difference between the market economies, transition economies and developing economies influences its implementation priorities. The mature economies pay attention to a sustainable building stock either by new construction or by refurbishment. In the transition economies the emphasis is on new developments reducing the housing shortage and improving their transportation networks. In the developing economies the social agenda (e.g., job creation) is much higher on the agenda than environmental concerns.

In addition to the "common" sustainability criteria, such as energy efficiency, non toxics or recyclability many other important sustainable measures can be listed. Some examples of that kind are: preserving property value, flexibility, long service life, use of local resources, information dissemination, use of by-products, immaterial services, mobility consideration or supporting local economy (Bourdeau et al. 1998).

The building industry has to adapt to these new and emerging construction markets which have environmental and social dimensions. Construction businesses are expected to integrate into, and consider more fully, the issues valued by others at national, regional and community level where the driving forces will be a mixture of political, social and market forces, requiring products which respond to genuine needs and concerns.

Selected examples of sustainable construction implementations (Bourdeau et al. 1998) from different countries are presented in the following:

- **National package for sustainable building** (the Netherlands[4])

  A national package for sustainable building has been drawn up by the building industry and is aimed mainly at the residential market. The State Secretary for Housing, Spatial Planning and the Environment has added a recommendation that should give substance to the principle of sustainable building from 1996. Thirteen organizations were involved in drawing up the national package for sustainable building. The national package consists of some 160 voluntary measures. The involvement of many trade associations and the clear nature of the package mean that it should become a standard for everyone.

- **Ecological criteria for experimental construction** (Finland[5])

  The City of Helsinki and the Eco-Community Project organized a design competition for experimental housing in a rural area including ecologically sensitive and valuable protected waterfronts near the center of Helsinki. The competition aimed to save nature and natural resources, to have a high quality with regards to their architecture and functionality of the dwellings, and to be feasible to construct. A group of building consultants devised a tool for the ecological assessment of building designs defining minimum ecological levels for building and estimates about the ecological degree of development projects.

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- **Habitat for humanity** (United States[6])

  Habitat for Humanity is a non-profit non-denominational religious international organization devoted to construction of 10.000 low income housing units annually. The group sells completed homes to qualified participants with interest-free loans. Participants are obligated to contribute personal sweat-equity in the construction of both their own home as well as others, along with community volunteers and vendors who contribute labor and materials. Homes are constructed over the course of several weekends when a full crew of dozens of volunteers assembles for intensive housing-raising sessions. The Jordan Commons project of 200 low income homes with the principles of community, community services, energy-efficiency, and affordability made it a comprehensive approach to sustainable development. Specifically, the ideas of environmental responsibility, economic viability, and social equity are combined in one project using housing as a foundation.

- **Straw bale farmhouse** (United Kingdom[7])

  This straw farmhouse, costing in the region of 15.000 GBP, is situated in a small village in mid Wales. It is built with large bales of tightly compacted straw, and sits on a concrete foundation. The house will be centrally heated by a solid fuel stove attached to a boiler, but as the straw bales are estimated to provide ten times more insulation than manufactured blocks, the house is very energy efficient. The building’s roof will be insulated with wool, supplied by the farm’s own sheep, and is built from wood cut from a nearby forest and machined by a local supplier.

- **Internet office and ecohouse pavilion** (Ireland[8])

  This project was completed in 1995 and provided an imaginative extension to an existing building which included many special features. State-of-the-art environmental technology was incorporated in the design including PV cells, low pollution, breathing materials. The pavilion is south facing in order to maximize the passive solar energy and an existing well was incorporated into the design to allow for irrigation of a year round vegetable garden as well as for cooling purposes.

- **The recycled house** (Belgium[9])

  This project concerns the construction of a demonstration building incorporating a significant proportion of new materials derived from recycling building debris and from the reuse of waste or by-products from other industrial sectors. The goal is to demonstrate the it is possible in the construction sector to make use of a high proportion of recycled materials without harming in any way the functional properties of the building or without increasing the construction costs.

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- **Environmental symbiosis building** (Japan[10])

  The Japanese traditional culture involves the paradigm of harmonization with nature. It is acceptable for Japanese people to define the man as only one of the players in the environment. Based on these cultural bases, the word of environmental symbiosis building is more frequently used than sustainable building, environmental conscious buildings and green buildings in Japan. Housing and Urban Development Corporation and local councils are now constructing environment-friendly estates nation-wide. Fukasawa Housing Complex in Tokyo is a typical example of an environment symbiosis building.

- **Passive design** (South Africa[11])

  Apart from measures involving the orientation of the building and using materials in a way that makes the most of natural energy, lighting and temperature control, the house also uses passive solar design to regulate internal air temperatures. The building uses a combination of a large skylight on a north-facing roof, situated above a heavy concrete floor finished in terracotta tiles. The tiled floor acts as a heat sink, absorbing the heat entering via the skylight, and releasing it at night or in winter months. Large, adjustable blinds below the skylight prevent excessive heat gain in summer.

- **Urban regeneration and rehabilitation** (Romania[12])

  The core of this project is based on the refurbishment of apartment blocks built in the 1960's which provided the most basic living conditions. The main objectives of the project were to improve living conditions and the external outlook. The choice of rehabilitation resulted in costs accounting for only 45 % of the costs of new build. The following improvements have been achieved: 25-30 % increase in living space, improved thermal insulation, improved quality, updated infrastructure, new storage space, improved external aesthetics.

- **Energy saving elementary school** (Italy[13])

  The occupancy of the rooms is both various and impermanent: classrooms are used to a greater or lesser extent according to their function; the length of a school day is generally shorter than a working day but extra education courses result in the extension of energy utilization in any given day. The energy saving strategy in the school building includes: ventilated roof, super-insulation of walls and roof, insulating glazing, natural ventilation, thermal bridges, buffer space and special glazing.

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[13] source: Roberto Bologna, Univ. of Florence. Fax: + 39 55 2347152

- **Energy and water management** (France[14])

  A block of flats and five houses have been built in the East of France in a small village of 1.000 inhabitants. The owner has looked for decreasing the service charges and has given importance to energy and water saving. Three technical solutions to collect and store rain water have been envisaged: A total collecting of rainwater above the upper floor with a gravity distribution to all toilets; A storage under the first floor with a pump and surpressing device; A mixed solution with a small pump ensuring the water transfer to the storage.

- **Air conditioning system** (Spain[15])

  The building is the result of remodeling old military barracks. It has strong air conditioning requirements. During most of the year, a simultaneous provision of cooling and heating is needed. The solutions adopted in the building include the use of the free-cooling system, cold and warm radiating ground, individualized air conditioning system for each space and management of the air conditioning and lighting systems based on presence detectors and computer control.

These examples of good sustainable construction innovations, and many more from all over the world, international agreements, and national and local initiatives towards sustainability foster the belief that the change has started. Good examples can also be taken from the corporation side, such as the World Business Council for Sustainable Development (WBCSC[16]), a coalition of 125 international companies having members from 30 countries from more than 20 major industrial sectors, forming a global network. WBCSC promotes eco-efficient leadership linking business and environmental excellence. Another example is the President's Council on Sustainable Development (PCSD[17]) that sparks national dialogue in the US on sustainable development. However, it must be said that a solid methodology for implementing sustainable construction still lacks.

CONTRIBUTION OF LEAN CONSTRUCTION

PRINCIPLES OF LEAN CONSTRUCTION

Conventional engineering and production approach is based on the conversion view. The concurrent engineering approach (Table 2), applying the principles of lean production (Koskela 1998), stresses the flow view and the value generation view, in addition to the conversion view (Koskela & Huovila 1997). Lean design, or concurrent engineering, is mainly dealing with information processes, whereas lean production emphasizes material processes. Therefore, the sustainability contribution of the flow view (eliminating waste), is crucial in production, whereas in engineering, the value view is crucial.

[14] source: Luc Bourdeau, CSTB. e-mail: l.bourdeau@cstb.fr
[15] source: Pere Alavedra, UPC. e-mail: alavedra@ec.upc.es
[16] http://www.wbcsd.ch
[17] http://www.whitehouse.gov/PCSD

Table 2: Conceptualization of engineering and production

	Conversion view	*Flow view*	*Value generation view*
CONCEPTUALIZATION	As a conversion of requirements and constraints into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
MAIN PRINCIPLES	Hierarchical decomposition; control and optimization of decomposed activities	Elimination of waste (non-conversion activities); time reduction	Elimination of value loss (achieved value in relation to best possible value)
PRACTICAL CONTRIBUTION	Taking care of what has to be done	Taking care of that what is unnecessary is done as little as possible	Taking care of that customer requirements are met in the best possible manner
SUGGESTED NAME FOR PRACTICAL APPLICATION	Task management	Flow management	Value management
SUSTAINABILITY NOTICE	**Management of the life cycle requirements**	**Waste elimination**	**Environment is the customer**

CONTRIBUTION TO SUSTAINABLE DEVELOPMENT

In the traditional *conversion view*, the requirements are converted into product design. It is then essential to meet the requirements and *add value* to the customer.

In the *flow view*, the waste activities are eliminated. Elimination of material waste meets directly the sustainability objectives.

In the *value generation view*, the process aims at adding value to the customer. The key question is: who is the customer?

The principles of lean construction converge to the sustainability objectives:

- **Eliminating (material) Waste**
  ➪ minimization of resource depletion, minimization of pollution
- **Adding Value to the Customer**
  ➪ minimization of resource depletion, minimization of pollution, matching business and environmental excellence.

EXAMPLE OF SUSTAINABLE VALUE GENERATION

One example of different priorities of different customers is illustrated in Figure 3. In some projects it may be most important

- from the *owner's* and *user's* point of view to emphasize:
  Conformity to business processes; Location; Life cycle costs; Indoor conditions, because the decision of investment is based on these criteria
- from the *environment's* point of view to concentrate on:
  Environmental burdens in operation; Service life and risks for deterioration; Convertibility and flexibility, because they form the major burdens to the environment during the life span of the facility

- from the *contractor's* point of view to look at:
  Safety; Comfort; Embodied environmental burdens in building elements, because they may have the strongest direct influence on the construction costs in some cases.

If the owner and the contractor have different sustainability priorities, that both differentiate from the environmental priorities, it may at a short term lead to non-optimal trade-offs from the environmental point of view. At a longer term, however, the sustainability objectives will converge and the industry's responds to environmental problems may, in fact, be a leading indicator of its overall competitiveness. Successful environmentalists and companies will reject old trade-offs and build on the underlying economic logic that links the environment, resource productivity, innovation, and competitiveness (Porter et al. 1995).

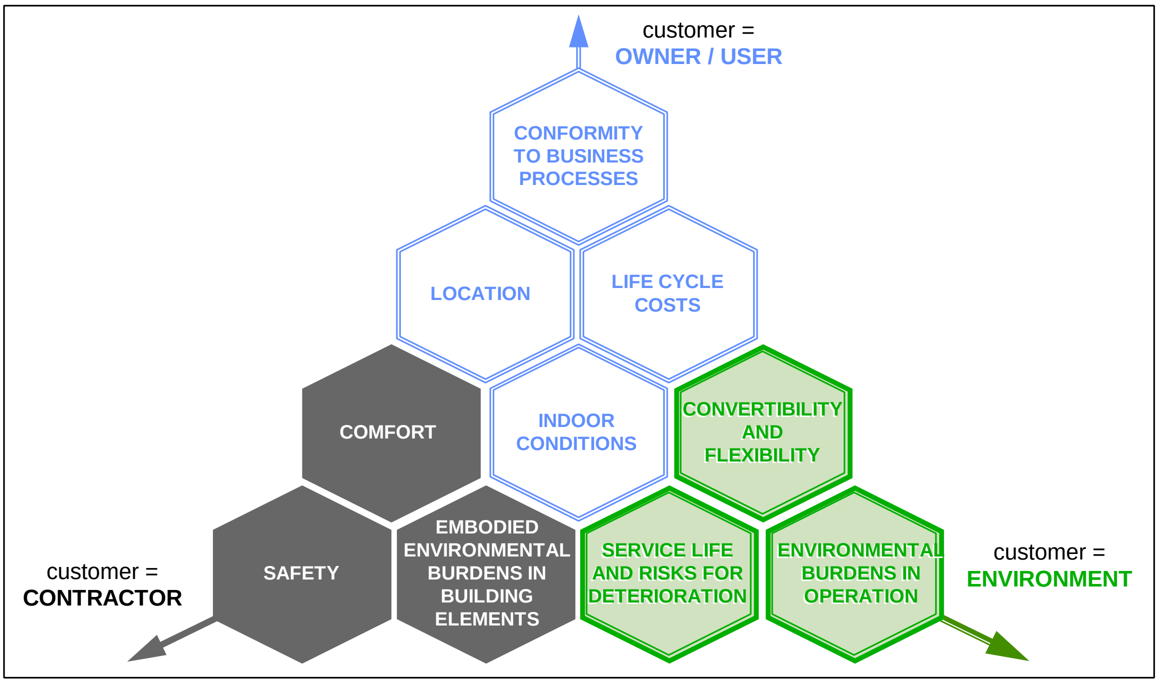

Figure 3: Classified requirements for a facility and their possible priorities for different customers

REQUIREMENTS FRAMEWORK

A requirements framework that is developed at VTT Building Technology, VTT ProP, is presented in Table 3 as an example of related development. The framework is generic, well applicable also for sustainable buildings. The structure is compatible with relevant Master lists, such as the Green Building Challenge '98[18].

The objective is to use a classified list of required properties of a facility in order not to miss the requirements early in the process. The higher level requirements are opened and explained in more detail at a lower level. Each property is expressed in the form of specified requirements and an indication of the process phase when those requirements

[18] http://www.greenbuilding.ca/GBIC.html

should be set. Values and classes of the requirement are referred to, and methods for verifying the conformity both in building design, and in the constructed facility, are suggested. The framework can be applied for all kinds of buildings and materials, its lower level content altering correspondingly.

Table 3: Requirements framework named **VTT ProP** (only main titles presented)

required property	*specified requirement*	*process phase*	*value or class*	*verifying method*
CONFORMITY TO BUSINESS PROCESSES ☆ core processes ☆ supporting activities ☆ image				
LIFE CYCLE COSTS ☆ initial costs ☆ administrative costs ☆ maintenance costs ☆ costs from fundamental improvement				
LOCATION ☆ site properties ☆ traffic communications ☆ services ☆ environmental impact from land use				
INDOOR CONDITIONS ☆ indoor air quality ☆ sound insulation and noise reduction ☆ lighting				
SERVICE LIFE AND RISKS OF DETERIORATION				
CONVERTIBILITY AND FLEXIBILITY				
ENVIRONMENTAL BURDENS IN OPERATION ☆ energy and water consumption and emissions of building ☆ energy and water consumption and emissions caused by users				
EMBODIED ENVIRONMENTAL BURDENS IN BUILDING ELEMENTS ☆ energy, raw materials and emissions ☆ recycling				
SAFETY ☆ constructional safety ☆ fire safety ☆ safety in service ☆ burglar safety ☆ safety against natural catastrophes				
COMFORT				
EFFECTS ON NEIGHBORING SURROUNDINGS				

DISCUSSION

Sustainable construction is a new concept that requires considering the sustainability objectives for all decision making during the life cycle of the built facility. The concept of sustainable development has different priorities in different economies, but good examples of its implementation can be listed the globe over. The theory of lean construction is already offering the conceptual basis, and potential for novel methods and tools for sustainable construction. Joint efforts are called to spur further development to improve our quality of life through sustainability.

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