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TECHNOLOGICAL CAPABILITIES FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT

Theoretical views point at the status of technological capabilities as the major factor that determines the production performance and the sustainability and competitiveness in industries. Technological capabilities refer to the total stock of technological resources in an industry that can be committed to the production processes. A methodology was developed to determine the state of art of the technological capabilities in an industry. Case studies were carried out by using the methodology . The results were useful to support the enhancement of the manufacturing and application of sustainable Construction Technologies. Empirical evidence indicated an under utilisation and a wrong utilisation of the available resources for sustainable building construction in countries. This paper describes the results of a case study that was carried out in the Costa Rican dwelling construction industry. Recommendations could be given for the enhancement of the manufacturing and application of sustainable innovative Construction Technologies.

KEYWORDS

Technological Capabilities, Construction Technologies, Sustainability, Dwelling Construction

1. INTRODUCTION

During the last decade of the twentieth century a lot more consideration has been given to sustainability aspects in production than has been before. The world has become aware that something has to change regarding the present economical and consumptive development. Sustainable development as defined by the.WCED (WCED 1987) is understood to be essentially a goal or vision that forward looking organizations should be striving after. The environmental, social and economic goals of sustainable development should be integrated and balanced with the sensibility that the 'perfect' solution does not exist.

The construction industry has a major role to play in the delivery of sustainable development through its activities, whether it is the provision of buildings, infrastructure development or contaminated land reclamation. The challenge for the industry is to play an integral part in providing a better quality of life through its activities, whilst minimizing impacts on the environment and local communities. However construction activities also can have a severe negative impact like ecological deforestation and air pollution. For example more than 50% of the extraction of natural resources is by the construction industry in the world. In the UK about 17% of waste going to landfill sites is directly related to construction. Europe 40% of the energy utilization is related to construction. (Boonstra 1996). In Costa Rica 9,6% of all emission of CO_2 is due to the cement production.(MINAE 1995)

Plenty reasons to focus research on sustainable construction, which may be defined as building practices that strive for integral economic, social and environmental quality in a very broad way. An important question that rises immediately thereafter refers to the major factors that have an impact on sustainable construction.

This paper describes our investigation of the status of technological capabilities, which is in literature indicated as the major factor that determines the production performance, the sustainability and competitiveness in industries. In the sections that follow the concepts of sustainable development, production and technology in general as well as in building practices in will be discussed first emphasizing the role of technology in these. Subsequently the concept of Technological Capability will be introduced as well as its meaning for sustainable construction. These theoretical views form the basis for the Technology Mapping Methodology (TMM) that we developed as an integral method for the analyses of technology and technological capabilities to support the formulation of technology policies for sustainable development. The TMM was used to investigate the sustainability of building practices in Costa Rica as well as the state of art of the technological capabilities. Based on the major findings that are described in section 6 and 7 an afterthought is given regarding the path that should be followed to improve sustainable construction through Technological Capability Building.

2. SUSTAINABLE DEVELOPMENT, PRODUCTION AND TECHNOLOGY

Sustainable development is all about ensuring a better quality of life for everyone, now and for future generations, through: social progress which recognizes the needs of everyone; maintenance of high and stable levels of economic growth and employment, whilst; protecting, and if possible enhancing, the environment, and using natural resources prudently. (WCED 1987, WWF 1991) Sustainable development embraces the three broad themes of environmental, social and economic accountability.

Sustainable production leads to the achievement of a sustained social development in a country by using resources in such way that these resources are not depleted or permanently damaged. An efficient and optimal deployment of resources in a country implies the need for industrial production, which means a systematization, standardization and rationalization of the production processes. It is a common wisdom that the establishment of healthy industrialized production calls for an adequate utilization and development of sustainable technologies.

Sustainable technology is a concept that refers to the range of technologies applicable in production processes that contribute most to the achievement of economic, social and environmental goals in relation to resource endowments and conditions of their application in a country. The technology thus is expected to contribute to traditional capital accumulation and at the same time to preserve, restore and enlarge the ecological, socio-cultural potential in a country.

3. SUSTAINABLE CONSTRUCTION AND TECHNOLOGY

Alike in any other production process, construction process technologies are used to transform the material inputs into the desired output. Inputs in building construction process consist of natural resources, intermediate products like building materials, building components and/or complete prefabricated building elements and energy.

Construction process technologies consist of a complex of four components: Object embodied technology (Facilities or techno ware), (2) person-embodied technology (Abilities or Human ware), (3) document embodied technology (documented facts or infoware), (4) organization embodied technology (frameworks or orgaware) The construction process -alike any production process- only can take place when a minimum is present of all four components of technology. All four components can be marketed separately. (UNESCAP 1989) For every construction project it is possible to choose from several possible combinations of process technology components that fit the terms of reference for the quality and the quantity of the final construction output.

The output of the construction process (the building) is characterized by a coherent complex of product technological attributes of an interdependent group of items (products of foregoing production phases such as those in the building materials industries) that form the unified whole of the building and that determine the nature, appearance and costs of the building.

In line with the above can be concluded that sustainable construction calls for an adequate development and utilization of technologies by which an efficient and optimal deployment of the available resources is secured, in such way that the social and natural ecological environment for the present and future generations in a country will not be harmed. Adequate technology management is thus important for sustainable construction.

4. TECHNOLOGICAL CAPABILITIES

An important question that rises refers to the factors that have an impact on the development and application of technologies for the achievement of sustainable construction. An answer can be found in the views that emerged by the late 1970's when the neo-classical economic theories in the field of technology related industrial development studies began to loose much of their appeal. Following these ideas, the bottleneck to properly formulate and implement national development policies to support and improve production is formed by the absence of *capabilities*. Technological capabilities include the potential of nations, organizations and enterprises to: (1) expand the production output, (2) meet the demand for local and/or new products, (3) switch to new production lines, (4) make new investments, (5) upgrade managerial organizational skills, (6) eliminate deficiencies in skills and know-how in the labor force, (7) facilitate the access to information and documentation, (8) enhance technological advancements and (9) make use of and upgrade existing (small scale) production. In other words, the competitiveness of a nation and its ability to follow the rapid pace of social, economic and technological development in a sustainable way, depends on the capabilities to utilize, maintain and upgrade technology. (Fransman 1984, Lall 1987-1990, Rosenberg 1982, Romijn 1996, Stewart 1977-78)

These capabilities should exist in a technology infrastructure which is a network of more or less interrelated organizations, institutions and enterprises in a country. Due to lack of a strong technology infrastructure, a country may fail to use its scarce resources efficiently, resulting in rather high costs to enterprises and to the national economy. This implies an inefficient use of the existing resources, a declining productivity over time, a high and continuing degree of dependence on imported inputs and of technologies from abroad, a lack of local technological infrastructure and therefore limited integration in industry. (Rosenberg 1982, Sagasti 1979)]

The conclusion based on the above is that the state of art of technological capabilities is a key-factor for sustainable production. (Porter 1990) Consequently the conclusion is that a most obvious route to sustainable development should be technological capability building. Adequate technology management and policy making is needed for technology capability building to achieve an increased competitiveness and sustainable socio-economic growth. This on its turn requires insight in the explicit status of technological capabilities in production sectors.

Technological capabilities have been defined in numerous ways. In our definition that is considered useful for the investigation of sustainability in production and construction technological capabilities refer to the *national stock of resources* that can be committed to production, which includes the stock of (a) technologies, (b) human resources, (c) natural resources that is embedded in a technology infrastructure. (van Egmond 1999)

5. THE TECHNOLOGY MAPPING METHODOLOGY

A first requirement for technology management for sustainable construction is the availability of a full set of information on the current status of technological capabilities and the technologies to be able to distinguish the opportunities problems and constraints for improvement.

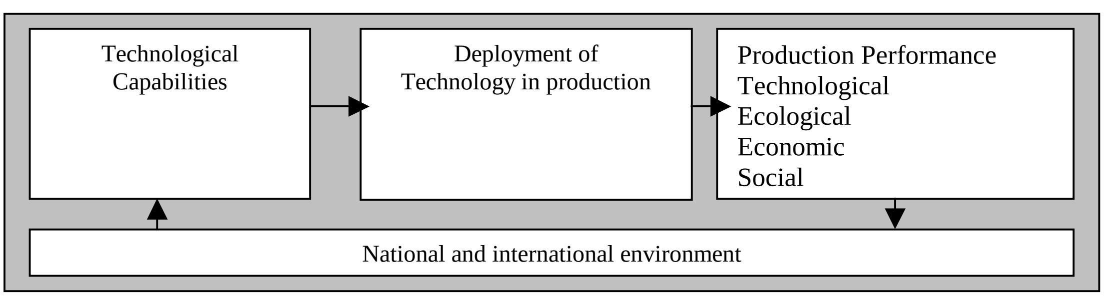

Figure 1: Theoretic Model

The foregoing presented views form the basis of a theoretic model that we developed as an integral method for the analyses of technology and technological capabilities to support the formulation of technology policies for sustainable development. It may be concluded that an integral method for the analysis of resource and technology utilization in production systems in their respective environments at different levels of aggregation (micro, -meso-, macro- and supra-macro level) is necessary to achieve an appropriate formulation and implementation of technology policies and strategies in a country. An investigation of the sustainability of industries includes a number of sub-studies which are necessarily of different disciplinary nature and mutually supportive to yield complementary data. This is to ensure a meaningful integration of the various socio-economic, technological and ecological aspects regarding sustainable production.

6. SUSTAINABILITY OF DWELLING CONSTRUCTION IN COSTA RICA

6.1 The Case Studies in Costa Rica
In the following sections of this paper the results are presented of our study on the sustainability of dwelling construction for lower income households in Costa Rica. Two types of construction technology systems used in lower income dwelling construction projects were investigated in detail: a concrete and a prefab bamboo construction system. The houses were all single storey urban houses, that had a rectangular shape with hip and gable roof and an average floor space of 40m2. (CIVCO 1993) van Egmond 1999, Lara 1995)

6.2 Construction Process Inputs
The figures on cement consumption show that the utilization of relatively new building materials and construction systems has increased rapidly in Costa Rica. Cement is produced locally. Also organic materials like timber and bamboo are locally available. However the construction industry heavily relies on imports of materials mainly from the United States due to the limited availability of local mineral resources. Steel products as well as plastics and chemicals (as intermediate products) for the construction industry have to be imported. MIDEPLAN 1996)

Concrete based construction systems are applied in more than 90% of the dwelling construction projects. The concrete blocks construction system is the most applied system in Costa Rica. next to prefab concrete panel systems. A minor market share (3%) is taken by the newly developed prefab bamboo based system which exists of light weight easy to handle prefab panels made of bamboo strips in a timber frame. The panels include window and doorframes. (van Egmond 1999)

6.3 Construction Process Technologies
Although Costa Rica has been able to develop and apply more advanced construction systems, the majority of the currently applied dwelling construction systems are still rather traditional and labour intensive and the degree of technological efficiency regarding the utilization of process technologies in the dwelling construction industry is in-sufficient. The trend in changing the construction technologies drastically is not strong. A major obstacle for technological efficiency is formed by the lack of skills and knowledge of the labour force on the construction sites and their commitment to the construction project since most labour is hired on temporary basis. The last aspect is less the case for the projects carried out with the bamboo system where the labour force is recruited from the households which will be the future owners of the houses.
Most dwelling construction projects for the lower income households are built by small and medium scale contractors. The availability of documentation and information on progress control techniques, manuals of machines, construction procedures, norms and regulations, and databases regarding material and equipment is generally reasonable on site. Time planning procedures, specifications of machines and documents of former projects are not very common and certainly not computerized. Training on the job is the most common form of training certainly for the semi-skilled and unskilled laborers. Research and development activities are not common among the contractors and predominantly take place at random or ad hoc part time basis. Contractors co-operate very occasionally with other organizations. The majority of relations they have are through the "Cámera Costarricense de Construcción". Only the middle-sized and large companies are member of this branch organization. (van Egmond 1999)

6.4 Technological Performance
The output of the investigated dwelling construction projects in terms of technological performance meets the requirements described in the Costa Rican building regulations for 70%. The technological production performance of the bamboo system is more than 50% better than that of the projects with the concrete blocks system and 20 % better than that with the prefab concrete system. Durability of the bamboo system against mechanic and physical forces wind loads and seismic forces is extremely good in contrast to the concrete systems that still are vulnerable to damage despite necessary precautions like reinforcement. Against biological influences (fungus, termites, insects,

etc) the bamboo system requires careful preservation but gets a reasonable protection by plastering of the bamboo panels.

6.5 Ecological Performance

The eco-indicator 95 that was established for the Dutch construction systems has been taken as an example to determine the Costa Rican ecological performance score. A consultation of a panel of experts in Costa Rica contributed to the establishment of a Costa Rican eco-indicator. (Thielemans et all 1997) The eco-score for the bamboo construction system was 31,2 against 70 for the concrete systems (0<eco-score<100). The Material utilization is for bamboo 55% less than for the concrete systems. The material components of the concrete construction system that cause environmental impacts count for 86 % of the major environmental impacts. (cement (40%), concrete elements (16%) and reinforcement steel(30%). This is in contrast with the relative costs of the material components in the concrete systems. A comparison of the costs of the material components of the concrete system shows that cement takes only 9%, the steel 8% and the concrete elements 17% of the total costs.

The use of cement in the finishing of the main structure of prefab bamboo panels counts for 59% of the total environmental impact and is the major cause of the negative environmental impact of the bamboo system whereas the cost proportion of the cement is only 11% of the total construction costs. Moreover the major negative impacts are formed during the phases of extraction of raw materials and the production of the intermediate products for the bamboo system. An ecological improvement of the bamboo system comes down at a reduction of the proportion of cement and steel in the construction system. (The remark should be made that in this research project only the major structure of the houses have been taken into account leaving out of scope. the roofing structure and the final finishing of the houses)

The negative environmental impact of the bamboo system houses is less then that of the concrete system, while the majority (>90%) of the houses still is built with concrete systems.

6.6 Sociological Performance

Costa Rica faces a tremendous housing problem in particular for the lower income households: over 200.000 houses are annually needed in the coming years. The supply of houses largely depends on the performance of the construction industry. The social production performance of the dwelling construction industry shows that only 16-18% of the actual housing need is met by the annual supply of the dwelling construction industry. An increased supply could be reached by decreasing the construction time for the houses. Building with the prefab concrete system requires the least construction time. The concrete blocks system projects are least time efficient.

There is a relatively low social acceptance of new construction systems such as the bamboo system. This is for the households due to their positive perception of the traditionally built houses with concrete blocks and a lack of information on the new systems. For the contractors the reluctance to built with newer systems is due to their in-experience with the newer systems, their uncertainty of the quality of the system, that may harm the construction time and the level of profit margin. Diffusion of information on the advantages and disadvantages of the construction systems should enhance the social acceptance.

The social performance of the concrete blocks is 85% better than that of the bamboo system, and 45% better than the prefab concrete system.

6.7 Economic Performance

The houses are unaffordable for the lower income households without subsidies from the National housing financing system (SFNV). The houses built with the bamboo construction system (US$4.500 -1997) are nearest affordable for the lower income households, next follows the Prefa PC system (US$ 4.700 -1997). The concrete blocks masonry system is the most expensive (US$6000) (Thielemans and van Egmond 1997)

The profit margin of the lower income housing projects for the enterprises is relatively low. A reason for this is that the terms of reference for the houses are rather tightly prescribed due to the fact that most of the lower income housing projects are carried out with support of the SFNV. The concrete systems offer the best opportunities for the contractors to get a reasonable profit margin. The total production chain from extraction of natural resources to final delivery of the constructed houses with the concrete systems is mainly a private sector business. This is different for the bamboo system.

6.8 Conclusion of a Comparison of the Sustainability of Concrete Systems versus the Prefab Bamboo System

The bamboo system performs technologically, ecologically and in terms of economic costs better than the concrete systems. However at present the social acceptance and the profitability of the systems for the contractor are more favorable for the concrete systems. It highly depends on the perception of the housing project managers and decision makers regarding sustainability which path is going to be followed for the development of the performance of the dwelling construction industry.

7. TECHNOLOGICAL CAPABILITIES FOR SUSTAINABLE CONSTRUCTION IN COSTA RICA

7.1 Technology Stock

The range of technologies available and utilized in housing construction in a middle income country like Costa Rica can be ranked in the intermediate class of technological advancement. The application of new construction systems implies that the actual production of the houses partly moved from the construction site to the factory. This happened in Costa Rica like in many industrialized countries. In Costa Rica only some 4% of the houses is still built on the traditional way by applying the timber and zocalo systems. Houses are in majority built with the conventional concrete blocks masonry system, and with the advanced prefab systems. The intermediate level of technological advancement is also reflected in the process technologies used on the construction sites

7.2 Human Resources Stock

The human resources stock represents the availability and the nature of manpower stock that is potentially available and employable in the sector. Costa Rica has a limited *population size* (ca 3 million) In Costa Rica (33%) belong to the *age group* that is younger than 15 years. The Costa Rican construction industry has the disposal of relatively enough managers and engineers but a lack of skilled labor on the project sites. A relatively high percentage (85%) of the labor force in construction is employed as craftsmen. Although the percentage of relatively young population in the country forms a reasonable potential of labor force for all productive activities, these resources are not fully exploited for the construction industry. A problem is the lack of training opportunities for the labor force on the construction sites. The percentage of scientists and engineers of total population is relatively low in Costa Rica (0,006%), which is a constriant for R&D activities. (UNESCO 1995)

7.3 Natural Resources Stock

The land area of Costa Rica is limited. The internal renewable water resources are fairly available. 31.5 (1,000 m3/year 1990) (UNDP 1992) The low availability of the mineral resources, the limited financial resources and a relatively small local market in the country form a major constraints for the construction industry. Some 32% of the total imports in the country involve the imports of raw materials; 17% of total imports involve the imports of capital goods. Cement is produced locally and in majority used in buildings(92,7% of all walls; 63,6% of all floors 1995). All metal products are basically imported (metal roofing sheets are used in 99% of the houses). Deforestation (nearly 7% per annum) causes a rapid decrease of forest areas. (78% to 29% of the total land area 1950–1987). (MINAE 1990) Reforestation programmes included a programme for the cultivation and propagation of 500 ha of bamboo Guadua (Guadua Angustifolia), that provides the necessary material for some planned 7500 houses per year, 12 years after the stgart of the plantation.

7.4 Technology Infrastructure

The network of the dwelling construction industry in Costa Rica (private and public investors, consultants, materials and equipment suppliers, R&D institutes, educational institutes, financing organizations, government, branch organizations, labor organizations) is in fact reasonably functioning. This might be due to the relative small size of the country and its population. The role of the Camara Costaricense de Construccion (the chamber of commerce for construction) as liaison between the various actors is indispensable. Despite this, it needs improvement by giving a better access for the smaller contractors to this branch organization. The functioning of actors such as the educational institutes, the R&D institutes in the network however forms a constraint for sustainable construction. A major cause for this is the lack of financial resources that come from the government, which has to deal with a decreasing volume of resources itself. The public sector also is a major investor in housing for the lower income households through the national financing system for housing (SNFV). The performance of the sector is rather vulnerable for politic–economic changes in the country. Private sector investments in housing mainly are in housing projects for the middle- and higher income households.

7.5 Conclusions on the Technological Capabilities

a The *range of construction systems and process technologies* available for dwelling construction reflects an increased level of advancement that can be used to improve the sustainability of the construction industry. In particular the locally developed prefab construction systems offer reasonable opportunities

b. the *human resources potential* is under exploited

c. the rather limited *availability of natural resources* for construction -that even tends to decrease- forms a constraint for sustainable construction and at the same time a stimulance for technology development

d. the *technology infrastructure* is reasonably developed, while as the performance of some individual actors is lacking. This harms the development and diffusion of technologies for sustainable construction.

8. IMPLICATIONS FOR SUSTAINABLE CONSTRUCTION MANAGEMENT

The conclusions indicate that sustainable development of the dwelling construction industry has a potential and should get a high priority in the national development plans. Given the limited and even decreasing stock national resources (technological capabilities) a most obvious route to improvement of the sustainable performance of the dwelling construction sector should be sought in technological capability building: increase of the quantity and quality of the total complex of national resources that can be committed to the dwelling construction sector. This means that for sustainable construction management the focus should be on the following.

8.1 Development of the Technology Stock (Tstock)

Technology developments should take place, by either R&D or international technology transfers, focussed on the improvement of the socio-technological as well as the ecological performance of the construction industry. The last refers to the reduction of energy utilization, emissions and ineffective and in-efficient utilization of natural resources for the production and utilization of the building materials and construction systems in the construction processes on site. Enabling and stimulation of technology developments and their diffusion in the construction industry should thus be on the political agenda.

8.2 Development and More Efficient and Effective Utilization of the Available Stock of Human Resources

The potential of human resources stock should be better utilized. The lack of skills and knowledge among the labor force on site shows that the performance in the sector highly depends on the country's educational system. Only in case of the availability of an appropriate education system the local construction capacity can improve quantitatively, but - more important- also qualitatively. Training and education of the labor force improves the socio-technological properties of the houses and at the same time reduces the ecological effects such as solid waste production on the construction sites. Stimulation of training on the job could be a solution given the unfavorable economic situation in the country that harms the public education opportunities. This has been the case in the construction projects that use the bamboo system where the houses are constructed with the involvement of the communities and labor is trained on the job. The advantages are lower labor costs, commitment of future house-owners and technology diffusion and learning effects. The increasing number of graduates in architecture, civil- and building engineering provides human resources and an opportunity for R&D and technology development, consultancy and management. This forms an enhancing factor for the improvement of a sustainable construction performance in the country, provided that this potential is fully exploited, financing is available and the technology infrastructure is adequate to diffuse developments in this sector.

8.3 Development of More Efficient and Effective Utilization of the Available Stock of Natural Resources (NR)

The rather limited availability of *natural resources* for the construction industry forms a challenge for further R&D on the efficiency of the utilization of these resources in building construction., which requires on its turn effective and efficient action from the organizations in the technological infrastructure of the construction industry. The improvement of the proper selection, extraction, production and utilization of natural resources by means of technological development will safe guard the opportunities for present and future generations. The development and establishment of the bamboo plantations that offer the opportunity to substitute the utilization of timber to decrease deforestation and at the same time the CO2 percentage in the air is a good example.

8.4 Development of theTechnological Infrastructure of the Construction Industry (TI)

The reasonably functioning network (technology infrastructure) of the construction industry should be better utilized for the diffusion of new innovative technology systems, like the prefab construction systems. An improvement of the network of relations between the various participants in the construction industry will benefit the diffusion and utilization of the results of efforts to improve and develop technologies, human and natural resources. In the end this will be beneficial for an improved sustainable production performance. Broadening of the network of the construction industry with international relations may enhance technology transfers for an improved sustainable construction performance. International collaboration could contribute to the alleviation of the lack of performance of the individual actors.

It should be stated that the above mentioned recommendations comprise a complex set of actions that are largely interrelated. The availability of a stock of Human Resources in Costa Rica with a relatively high education level gives an opportunity for Construction Management to emphasize on a more efficient and effective utilization of these Human Resources for a further development and sustainable improvement of the Technology Stock.: building materials, construction systems and construction processes. This on its turn can benefit the efficiency and sustainability of the utilization of the natural resources. The national setting of the country –that is not very favorable - is largely determined by factors that are not directly manageable at sector level. This has to be taken into account for the implementation of the Technological Capability Building efforts. This implies that aspects of economic and politic-regulatory nature have to be considered and that additional studies have to be carried out in other sectors of the economy complementary to the studies in the construction sector.

However the type of studies and the methodology that was developed for these give a clear direction of priorities to be set to effectuate an improved sustainable living condition for the population.

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