Construction Technology Diffusion in Developing Countries: Limitations of Prevailing Innovation Systems

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Abstract: The diffusion of innovative technologies in the market is usually a complex and difficult process with a varying degree of success and the effects of the diffused innovative technologies are very un-balanced. The objective of our research is to gain insight into the reasons why the diffusion of innovative technology fails, even though they promise a superior performance compared to incumbent technologies. Drawing on innovation systems theories, we have identified and used the concepts of technological regime, actor network and technology sets to analyze technology diffusion in a case study in the dwelling construction industry in Costa Rica. The results showed bottlenecks in the prevailing innovation system that curtailed the diffusion of an innovative construction technology.

Keywords: Innovation system, Diffusion, Actor network, Technological regime, Construction industry

INTRODUCTION

A considerable variety of innovative construction technologies have been developed and became available over the last years in the global market. Globalisation and trade liberalization offer opportunities for industries and countries to "catch-up" on development by taking over innovative technologies from others. The diffusion of innovative technologies in the market is usually very complex and difficult. The degree of success varies and the effects of the diffused innovative technologies can be unbalanced. This also leads to a growing wedge between the relatively few successful countries and the large mass of others, which "reflects underlying structural factors that are very difficult to alter in the short to medium term" (Lall, 2003).

Many projects in developing countries (DCs) are carried out by foreign companies with a considerable amount of sub-contracting and other forms of collaboration between foreign and local firms, while many of the used construction technologies are imported (Drewer, 1997; UNCTAD, 2000; ILO, 2001). This provides opportunities for acquisition of experience and access to technology

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for firms in DCs. Yet many technological opportunities remain under-utilised and the diffusion of innovative technologies appear to be quite slow (Egmond and Vulink, 2005). The objective of our research is to identify and understand the reasons why the diffusion of innovative technologies fail, even though they promise a superior performance compared to incumbent technologies. An important insight from innovation system theories indicates that concepts of technological regime, actor network and technology sets are crucial to the diffusion and acceptation of innovative technologies. Drawing on these theories, we identified and used the above-mentioned concepts to analyse the (potential) diffusion trajectory of an innovative technology in the lower income house building i.e., "dwelling" construction industry in Costa Rica. Lessons learnt can help facilitate the management of innovation, and technology flows for the benefit of a more balanced construction industry development.

THEORETICAL CONSIDERATIONS

Innovation and Diffusion

Various scholars have attempted to explain the phenomena of innovation over the past decades by using innovation theories which are rooted in the broad field of evolutionary and institutional economics, and the sociology of technology (e.g., Metcalfe, 1995; Freeman, 1987; Edquist, 1997).

From this perspective, "innovation" is seen as a cyclic process that encompasses the development, diffusion and implementation of new competitive technologies (Figure 1). Technology itself is broadly defined as a combination of knowledge and skills embodied in products, with product technological characteristics and production processes that are composed of a complex of inextricably interrelated process technology components: technoware (equipment, tools, machines), humanware (manpower), infoware (documented facts) and orgaware (organisational framework) (Egmond and Kumaraswamy, 2003).

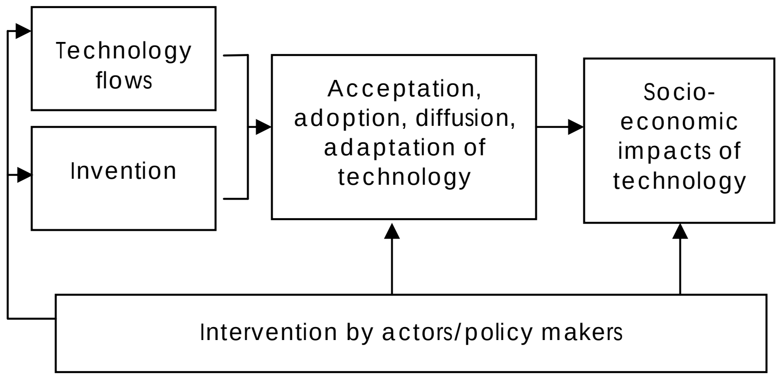

Figure 1. Innovation Cycle According to Egmond and Kumaraswamy (2003).

Innovations emerged in the course of time thanks to increasing levels of knowledge and technological skills, enhanced by continuous learning: accumulation, integration and mobilisation of knowledge and technological skills. This learning enables individuals and firms to create new possibilities through combining different knowledge sets (Tidd et al., 2005). Innovation implies change which can take many forms. There are various classifications of innovation that include product, process, position (of the products, processes and services in the socio-economic context) and paradigm innovation. The latter refers to changes in the underlying mental models which frame the boundaries of change options (Bessant and Tidd, 2007). "Diffusion" refers to the spread of novelties into society and is measured by the rate at which new technologies are adopted and applied in companies or institutions, or by people, causing the inventions to spread in society (Rogers, 1995).

Actor Network

Diffusion is accomplished through human interactions and communication between members of a community of practice (Rogers, 1995; Wenger, 1998). A community of practice is a concept similar to the actor network in an innovation system, which is a network of interrelated individuals, organisations and enterprises who share a common field of knowledge and interest regarding innovation in a certain domain (Malerba, 1999). It is the organisational environment in which innovation takes place as in Figure 2. These views connect well to the role attributed to social networks with regard to the rate of adoption in the diffusion theories tradition (Rogers, 1995).

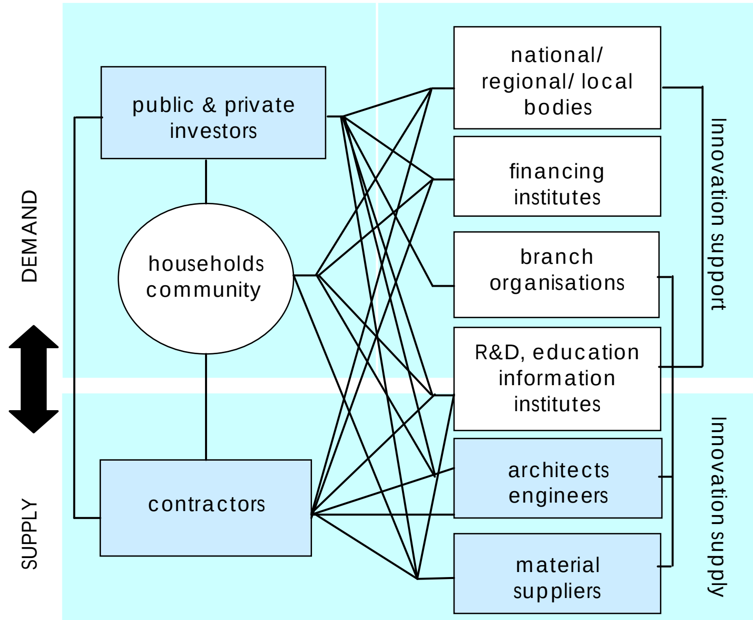

Figure 2. Outline of an Actor Network in the Construction Innovation System.

The interaction between the actors in the actor network gives rise to particular trajectories, which are sustained by industrial interests vested in it, assumptions about user needs and high costs of making a system change (March, 1991).

Technological Regime

Many innovative technologies are promising but stay undersupplied and are not used in the market, which according to Nelson and Winter (1982) can be interpreted on the grounds of technological regimes. Technological regimes are seen as social constructs: a pattern of knowledge, rules, regulations, conventions, consensual expectations, assumptions, or thinking shared by the actors in the innovation system. A technological regime defines the particular knowledge environment where innovation takes place. It embodies strong prescriptions on which directions to follow in innovative efforts and ensures that engineers and the firms for which they work neglect other technological possibilities, whereas it at the same time will define for the engineer what is feasible or at least worth attempting (Dosi, 1982; Nelson and Winter, 1982). In this sense, technological regimes set the boundaries and form a constraint to what can be achieved in innovative activities associated with a given set of production activities: and the directions (natural trajectories) along which solutions are likely to be found (Marsili and Verspagen, 2001). Thus, a technological regime guides the design and furthers the development of innovations (Dosi, 1982; Nelson and Winter, 1982).

From this perspective, it is stated that an innovative technology will be successfully diffused if it fits the prevailing innovation system; i.e., the actor network and the technological regime (Nelson and Winter, 1982; Douthwaite, 2002). If not, then a regime shift should be accomplished. This is a significant, profound and irreversible change from one fundamental view to another, a different model of behaviour or perception (Nelson and Winter, 1982).

Innovation System

Innovation does not take place in isolation but in an innovation system which is the social and economic context around the innovation (Von Hippel, 1988). An innovation system is seen as a set of distinct institutions which jointly and individually contribute to innovation – i.e., the development, diffusion and implementation of new competitive technologies. It provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of "interconnected institutions to create, store and transfer the knowledge, skills and artifacts which define new technologies" (Metcalfe, 1995). These views also match the reasoning of the Social Construction of Technology (SCOT) theories which suggest that innovation is a process that can produce different outcomes depending on the social circumstances in which it takes place (Bijker et al., 1987). Most research using the SCOT theories are committed to an actor-centered approach. A basic criticism of Pinch and Bijker's original conceptualisation of the SCOT theories is that in their views, the wider socio-economic, cultural and political context in which technological development takes place only plays a minor role. Not only the social network of the directly involved actors and their technological regime, but also the wider macro level social context in which production takes place needs to be taken into consideration (Kemp et al., 1998).

The foregoing leads to the notion that an innovation system is embedded in a wider macro-level social context and encompasses basically three building blocks as indicated in Figure 3 : (1) a network of agents interacting in a specific economic/industrial area; (2) a set of competitive technologies, products, processes, services that fulfill specific need in markets; (3) a particular technological regime (Carlsson and Stankiewicz, 1991; Breschi and Malerba, 1997).

Meanwhile, innovation systems have been categorised into different levels of aggregation, such as national, regional, and sectoral innovation systems (Nelson, 1993; OECD, 1997; Malerba, 1999; Edquist, 1997; Edquist and McKelvey, 2000).

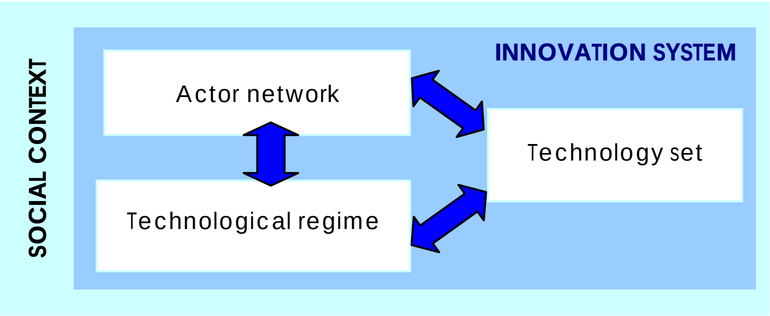

Figure 3. Innovation System Building Blocks.
Source: Adapted from Malerba (1999)

Technological Niches

Kemp et al. (1998) suggest that the diffusion of promising innovative technologies can be accelerated by taking care of incubation opportunities. Based on the SCOT theories, they developed views concerning technological niches according to the following line of reasoning (Kemp et al., 1998). Technological innovation is generally gradual and incremental and the set of technologies in a particular domain, such as building construction, together form a technological network. The technologies in this network, each with specific technological features, exist, or are developed alongside other technologies, whilst they serve a particular (limited) domain of application. Nodes of the technological network are the various existing and new technologies. The position of a technology in the network is its technological niche which is different from a market niche. The market potential (expected rate of return on investment) plays a role in technological niches. In a majority of cases, a successful diffusion and acceptance of an innovative technology needs a change in the prevailing innovation system since it generally does not directly meet the knowledge, rules, regulations, conventions, consensual expectations, assumptions, perceptions and objectives of all actors in the innovation system.

This is in particular the case when a new technology is introduced into an innovation system from elsewhere outside the system. The innovation system change can emerge from socio-technical "experiments," such as pilot projects in which innovative technologies are implemented, and in which various actors collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology. These actor interactions may then accomplish an adaptation in the technological regime (Kemp et al., 1998). Thus, by means of dedicated actions of "niche" leaders, regime adaptation and the diffusion of an innovative technology can be facilitated. Certain actors in the innovation system, such as policy makers, a regulatory agency, local authorities, a citizen group, private company, an industry organisation, or a special interest group, may be a "niche leader" who promotes a new technology. They might do this through offering the market opportunities to learn about the innovative technology by experimenting and doing (Arrow, 1962) and by using (Rosenberg, 1982; Von Hippel, 1988), by communicating and interacting (Lundvall, 1992). By doing so, they can bring about a regime adaptation and an innovation system change (Schot and Rip, 1996; Malerba, 1999).

Theoretical Framework

The theoretical considerations described above draw attention to the different components of a generic theoretical framework, which may help in analysing the diffusion and adoption (potential) of innovative technologies in the construction industry as in Figure 4.

This implies that multi component and multi level analyses have to be carried out, which are mutually supportive and necessary to understand the components that have an impact on the diffusion of innovative technologies in an innovation system.

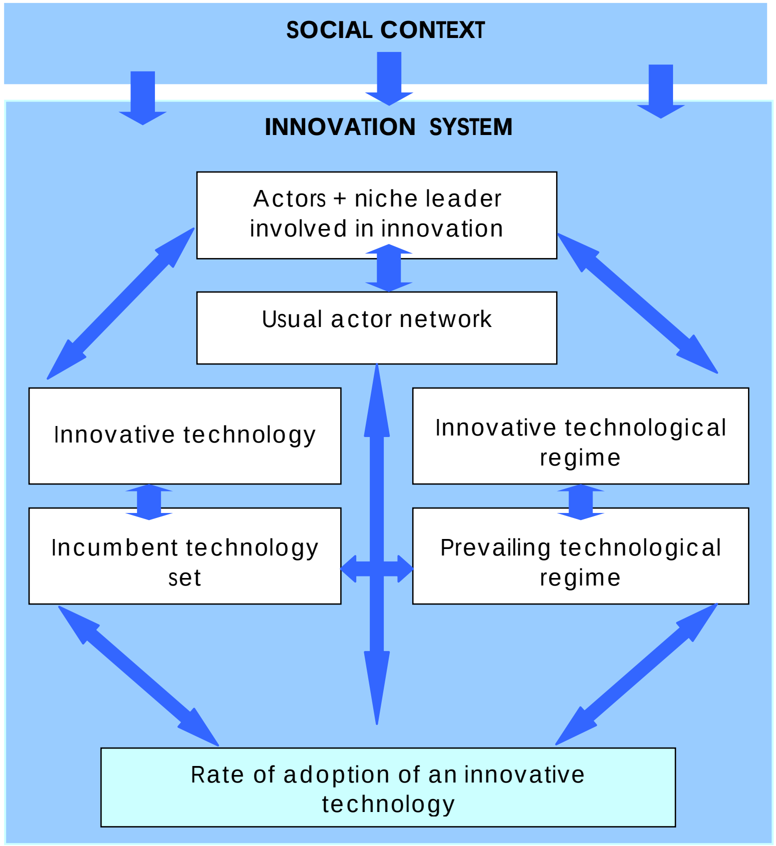

Figure 4. Theoretical Framework.

The first component analysis is to explore the set of construction technologies in the innovation system. Particular attention should be given to the degree of change of an innovative technology compared to existing technologies in the technology set. The second component analysis is to explore the usual actor network involved in construction, in order to systematically identify and document the composition and functional relation structure between the actors compared to the composition and functional relation structure between the sub-network actors involved in a particular technology innovation. The third component analysis is that of the technological regime compared to the professional practices and actor behaviour regarding innovative technologies. The fourth component analysis concerns the aspects of the macro level social context. These analyses help to assess the embeddedness of technologies in an innovation system, and they also may reveal the need for regime adaptations, for example by means of additional macro level policies to overcome barriers for the introduction of favourable innovative technologies.

RESULTS OF A CASE STUDY ON THE DIFFUSION OF AN INNOVATIVE TECHNOLOGY FOR DWELLING CONSTRUCTION IN COSTA RICA

The Case Study

The case study which is described in this paper is exploratory and primarily a field-mapping study that renders a systematic documentation of the prevailing innovation system of the construction industry – the technology set, actor network and technological regime in a selected DC: Costa Rica. It also serves to validate our methodological approach. We decided to undertake an ex-post case study on a promising innovative construction technology, which we knew had finally failed to "catch on" (i.e., not diffused as expected). The innovative construction technology comprises prefab lightweight bamboo panels for external and internal (partition) walls, floors and roof elements, which was developed and implemented in a number of projects within the framework of the National Bamboo Project that took place in the period 1986–1995. We made use of the data which we collected in the course of time and placed them within the previously explained theoretical perspectives. This enabled us to explore the features of the innovation system components, by means of traceable facts and factual contextual situations in the past. Several data collection methods were applied as in Table 1.

Mailed questionnaires were sent to contractors involved in dwelling construction projects i.e., house-building for lower income households in the period of 1994–1999. Structured personal interviews were also arranged to ask clarifying questions and avoid misinterpretations. A database of the Housing Mortgage Bank (BANHVI) on housing projects financed by them had been the starting point to identify the population of contractors involved in dwelling construction projects for lower income households. Experts of different institutes and organisations like the Instituto Technologico de Costa Rica (ITCR) and the Ministry of Housing (MIVAH) helped in identifying the lower-income housing projects. The identified projects should have had similar features with regard to: (a) the target group of the dwelling construction project which should be the lower income household, (b) the basic features of the dwelling, (c) the building sites which should be known as common residential districts. Through visits and phone-calls to authorised entities of the MIVAH, the building contractors and/or project managers of the listed dwelling construction projects could be traced. This resulted in a population of 17 building contractors and project managers involved in large scale dwelling construction projects, and 19 involved in individually built houses co-financed through government involvement. Information from the literature data and site visits were useful to compare questionnaire outcomes. Major sources of

Table 1. Data Collection Methods Applied During Field Studies in Costa Rica (1994–1999).

Methods	**Type of data + sources as documented in Egmond (1999)**
Literature studies	▪ General background information ▪ International, national and sectoral setting ▪ Product and process technologies in brochures website, etc. ▪ Detailed information on actors in lower income dwelling construction projects ***Sources***: *Costa Rican organisations and institutes (CIVCO, ITCR, UCR, CCC, MIVAH) + international sources e.g., World Bank and UN annual statistics*
Unstructured interviews with key-persons	▪ Additional information, not available from written sources ▪ Detailed information on features of dwelling construction innovation system ▪ Prevailing viewpoints and perceptions on performance of the construction industry, building materials and components ***Sources***: *Contractors,"key-persons" of institutes and organisations, e.g., ITCR, UCR, CCC, MIVAH, MUCAP, PNB*
Questionnaire & structured personal interviews	▪ Actor position and relations in the actor network ▪ Used construction technologies ▪ Prevailing technological regime: project objectives, viewpoints and perceptions on project performance, building materials and components. ***Sources:*** *Actors directly involved in the dwelling construction projects: contractors and clients/investors*
Visits, interviews & observation of building materials industry	▪ Particularities of utilised building materials ▪ Pre-fabrication and production ***Sources:*** *Several building materials industries e.g., PNB and PrefaPC*
Expert opinion	▪ Check the validity of collected data ***Sources:*** *Experts from ITCR, UCR, CCC, MIVAH, MUCAP, PNB*
Site-visits +non participant observations	▪ Cross check data during research project period of 1994 –1999. ***Sources:*** *Several project sites of lower income dwelling construction projects in Costa Rican urban areas*

additional data were the Instituto Technologico of Costa Rica (ITCR); Universidad de Costa Rica (UCR); Chamber of Commerce of the Construction Industry (CCC); Ministry of Housing (MIVAH); Cooperative Financing Bank (MUCAP); the National Bamboo Project (PNB); Prefa PC concrete panels industry (prefaPC).

Technology Set for Dwelling construction in Costa Rica

The major construction technologies traditionally in use for dwelling construction in Costa Rica are concrete technologies (> 90%); concrete blocks (CB) which is the most applied technology, and various prefab concrete column and panel systems with horizontally (PrefaPC) as well as vertically (Zitro) placed panels between the columns. A minor market share (3%) was taken by the innovative prefab bamboo (PB) technology for dwelling construction during the late 1990s (Janssen, 2000). The bamboo system is a modular system with industrialised prefabricated panels (2.5 x 2.7 m; 2.5 x 3.3 m; 2.5 x 1.8 m), composed of a frame of either bamboo or timber and a "lining" of cane or bamboo-strips of bamboo, as in Figure 5.

The panels are finished with three layers of cement plaster. The final appearance of the bamboo house is similar to that of the houses built with concrete technologies when it is finished with cement plastering.

Figure 5. Production of and Building with Innovative Prefab Bamboo Construction Technology.
Source: Janssen, 2000 (personal collection).

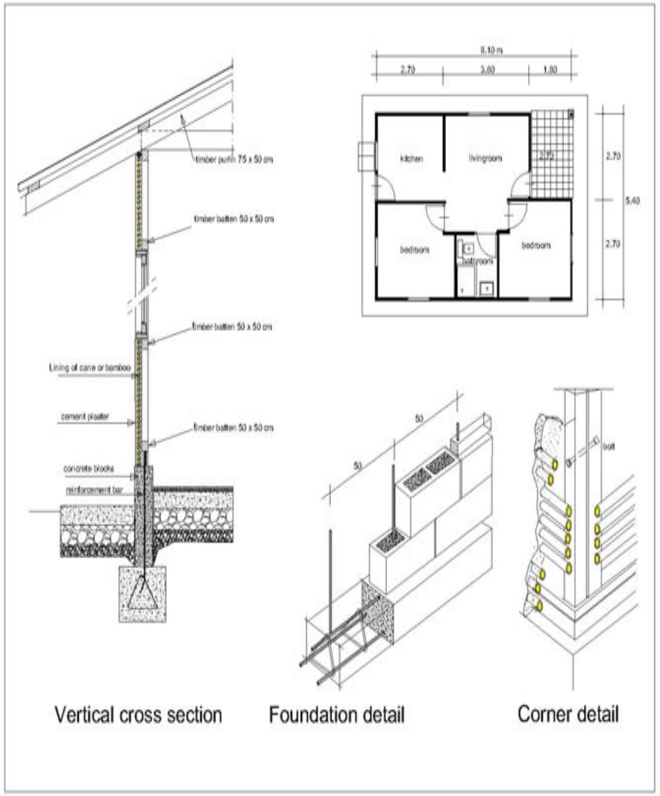

Figure 6. Floor Plan and Technical Drawings of a Basic Prefab Bamboo House.
Source: Vries (2002)

A 40 m[2] house (as in Figure 6) built with the prefab bamboo construction technology needs about 15 panels. The system allows all kinds of adaptations of the size and sub-division of spaces as required. Compared to the CB and Prefab Concrete Panel technologies, the Prefab Bamboo technology is rather flexible and easier to handle (manually) on site. The CB technology is most labour intensive. Although the Prefab Bamboo technology requires preservation against fungi, termites, insects, etc. as well as protection against fire risk, it scores better in an ecological sense as well as in technical durability against wind loads and seismic forces compared to the concrete technologies as in Table 2.

The costs for the houses such as the one in Figure 7 were in fact unaffordable for the lower income households without financing by the national financing system for housing (Janssen, 2000).

Table 2. Comparison of Low Income Dwelling Construction Technologies in Costa Rica.

Construction technology features	Concrete blocks	Prefab concrete	Prefab bamboo
Functionality (flexibility, multiple usability)	+	+	+
Load bearing capacity	+	+	+
Seismic resistance	-/±	±	+
Wind proof (properly anchored)	+	+	+
Biological durability (fungus, termites)	+	+	±/+
Thermal storage capacity	±	±	±
Rain-proof	+	+	+
Ventilation	+	+	+
Light weight (easy to handle, less material)	-	--	+
Maintenance	+	+	+
Equipment requirements on site (Technoware)	Simple tools	Heavy equipment and simple tools	Simple tools
Labour requirements on site (Humanware)	Skilled masons carpenters	Semi-skilled and skilled carpenters	Semi-skilled and unskilled
Instruction and information requirements (Infoware)	High	Medium	Medium
Organisational and management requirements (Orgaware)	High skilled	Medium	Medium
Construction time (on site)	3 months	2 months	1 month
Costs (1997)	US$6000	US$ 4700	US$4500

Legend : -- very bad; - bad; ± moderate; + good

Figure 7. Completed Prefab Bamboo Technology House.
Source: Janssen, 2000 (personal collection).

Actor Network Involved in Dwelling Construction in Costa Rica

In the usual course of events, the national government and its agencies act as the prime initiating actor and public sector investor in social housing in Costa Rica. Non-governmental organisations, private organisations, contractors and private households are mostly involved in housing projects for middle and higher income households. Innovation supplying actors are the architects, engineers, building materials suppliers and R&D institutes. Innovation supporting and regulating agencies are national, regional, local governments and public agencies, financing institutions, R&D and educational institutes, branch organisations, information centers, Chambers of Commerce, etc. Contractors in Costa Rica appear to have strong long lasting relations and are sometimes even part of the technology supplying and supporting organisations (see Figure 8).

Dwelling construction is dominated by the concrete building materials suppliers and contractors who predominantly build with concrete technologies. The total supply chain from extraction of natural resources to final delivery of the constructed houses with the concrete technologies is mainly a private sector business.

The actors involved in dwelling construction with the innovative bamboo technology represented a tight collaborative sub-network that includes the local communities. This sub-network lasted from 1986–1995 as in Figure 9.

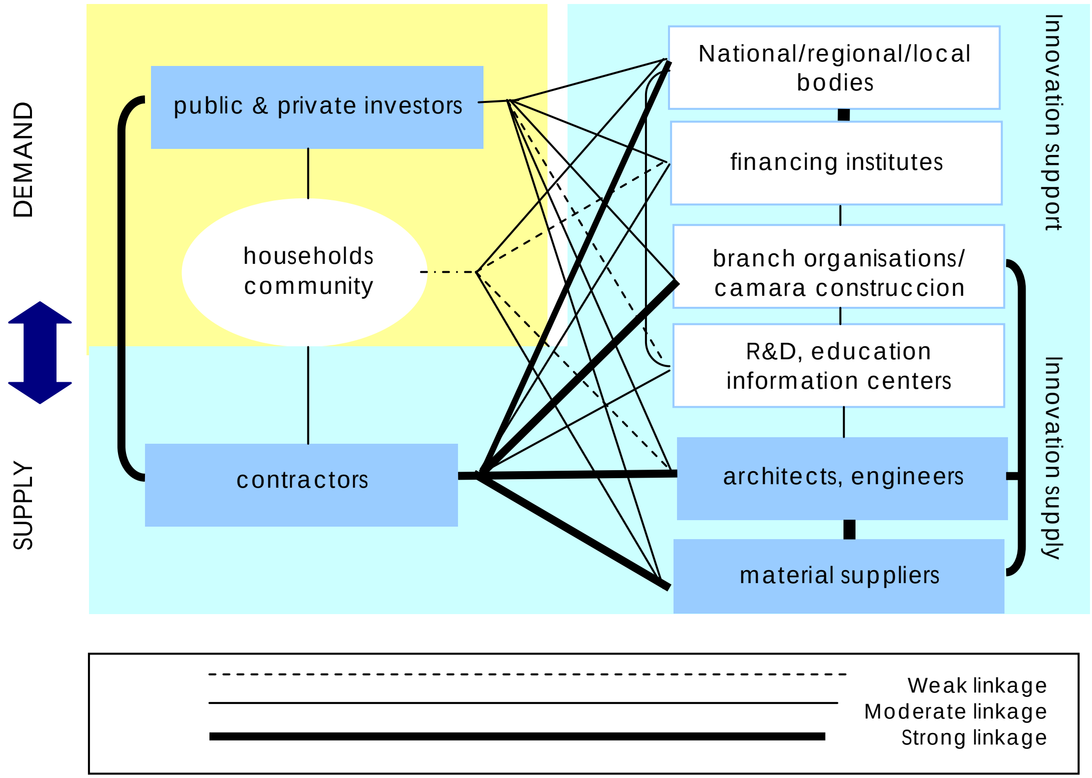

Figure 8. Usual Dwelling Construction Actor Network in Costa Rica.

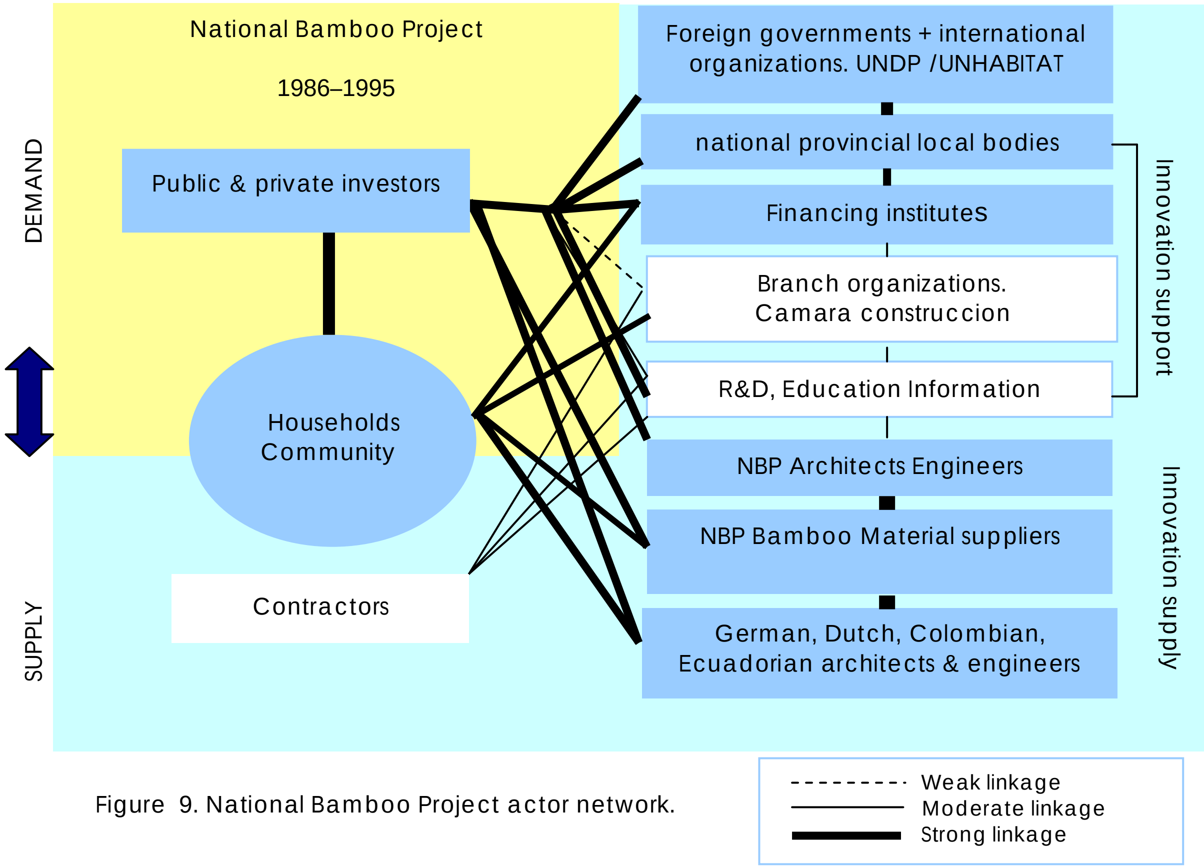

Figure 9. National Bamboo Project actor network.

The innovative Bamboo technology was developed within a non-profit project organisation, the National Bamboo Project (NBP, 1986–1995), which was the result of a public-private initiative with involvement of the Ministry of Housing and Human Settlements, and strongly supported by international organisations such as the Banco Centroamericano de Integracion Economia (BCIE), UN-HABITAT, the United Nations Development Program (UNDP) and the governments of Costa Rica and the Netherlands.

All actors needed in the production chain of bamboo dwellings closely worked together: the national, provincial and local governments and their agencies, financing institutions, local communities, architects, local and foreign engineers and consultants (from Germany, the Netherlands, US, Colombia and Ecuador) for bamboo cultivation, preservation and building construction. However, due to changes in politic-economic policies, the network was more or less dismantled in 1995, and instead, a (private) foundation "FUNBAMBU" was established.

Technological Regime Pertaining to Dwelling Construction in Costa Rica

Although Costa Rica has been able to develop and apply more advanced construction technologies in the course of time, the trend to drastically change dwelling construction is not strong. The actors involved in dwelling construction with the innovative bamboo technology appear to have formed a tight and closed sub-network with a technological regime that is specific and different from that in usual dwelling construction as in Table 3.

Macro Level Social Context

Costa Rica is a middle income country, which has a relatively limited investment capacity and thus has to rely in many cases on foreign investments and innovative technologies. The Costa Rican government acknowledged during the last decades of the 20th century that the activities in the NBP could contribute to alleviate the housing deficit, especially for low income families, as well as the environmental problems in the country. However, the political orientation changes nearly every four years, resulting in changing policies that may hamper on-going activities. Government agencies and the National Financing System for Housing prescribe tight regulations and specifications for houses co-financed by them, which leaves little room for architects and contractors to apply innovative technologies.

Table 3. Technological Regimes in Costa Rican Construction Industry.

	Amongst actors usually executing dwelling construction projects	**Amongst actors involved in development & diffusion of innovative bamboo construction technology (1986–1995)**
Objectives shared by network actors	▪ Quality of work ▪ Timely delivery of work ▪ Profit/cost efficiency ▪ Risk-free	▪ Introduction and implementation of innovative technology ▪ Sustainable construction–prevent deforestation ▪ Cost-effective construction ▪ Development and implementation of seismic sound construction technologies ▪ Solve housing problems especially for low-income communities ▪ Solve employment and income problems in low-income communities
Perception/ expectation of innovative technologies	▪ Fear for social change and needed investments for (1) training labour; (2)change organisational structure; (3) new equipment & tools ▪ Uncertainty of the quality of the technologies ▪ Harmful for construction time ▪ Harmful for profit margin, = small due to tightly prescribed specifications by government & National Financing System	▪ Traditional material in a modern engineering context ▪ Cost-effective ▪ Sustainable and ecological friendly ▪ Durable and strong – high seismic resistance ▪ Light weight ▪ Easy to handle and fast building ▪ Appealing
Knowledge/ learning	▪ In-experience with newer technologies ▪ Until 1986, Costa Rican universities and research centers knew little about bamboo and its various applications. ▪ Limited means for investment in training by construction firms	▪ Needed knowledge components for supply chain available amongst NBP network actors ▪ Experience with bamboo design and construction in Colombia and Ecuador ▪ Knowledge and skills with respect to bamboo engineering (Netherlands) ▪ Knowledge with respect to bamboo preservation (Germany) ▪ Knowledge with respect to local context, design and engineering (Costa Rica)
Professional practice/ behaviour with respect to innovative technologies	▪ Stick to traditional rules and conventions ▪ Stick to existing network and relations with suppliers & clients ▪ Preference for traditional, well-known technologies ▪ Preference for houses with construction technology equivalent to houses of the middle-class and upper-class ▪ Reluctance to adopt innovative technologies ▪ Relatively low social acceptance of novelties ▪ Reluctance to adapt the organisation and practices ▪ Low cultural acceptance of bamboo technologies	▪ Interest and motivation to reach together the same targets with innovative bamboo technology ▪ Investment in technical training, learning and capacity building up from each others knowledge and experiences ▪ Accomplish construction process, community and labour organisation changes ▪ Formation of community labour groups ▪ Collaboration and investment in massive bamboo cultivation (200 hectares) ▪ Collaboration and investment in intensive housing construction scheme in rural areas ▪ Collaboration in production of furniture and handicrafts for export ▪ Inward orientation on sub-network relations
Result	▪ Dwelling construction predominantly built with traditional concrete technologies (>90%) ▪ No extensive recognition of innovative bamboo technology	▪ 700 bamboo houses built + 200 hectares cultivated with bamboo ▪ Capacity building: 400 people trained in building, cultivating and crafting of bamboo ▪ Community participation ▪ Contribution to solve low-cost housing problems, unemployment, deforestation road repairs, supply of drinking water, improvement of health conditions ▪ Weak relations of NBP actors beyond their own network

DISCUSSION

The innovative technology in the case study is developed and exists alongside other technologies. It served as a particular domain of application and offered additional technical and social advantages compared to the traditionally used technologies in dwelling construction. The innovative Bamboo Technology flourished in the protected and supporting environment of the NBP (1986–1995) and its tight network, which can be considered as a technological niche. The project management of the NBP acted as a niche leader and created opportunities for the innovative bamboo technology to incubate and mature through gradual experimentation, technology and knowledge flows in the actor network of producers, researchers, users, governmental and other organisations which are tightly collaborating in the NBP. However, there was no great breakthrough of the Bamboo technology in the construction market after 1995. The failure of a widespread diffusion and implementation of the innovative bamboo technology can be attributed to the prevailing innovation system that obviously curtailed the diffusion as summarised in Table 4.

Table 4. Major Influencing Factors on the Diffusion of the Prefab Bamboo Technology.

Macro-social context	The socio-economic context and dependence on foreign and public financing for innovation Changing politic-economic policies during new period of administration in 1990s
Meso-level Innovation system	Rather strong traditional actor network in the Costa Rican innovation system of the construction industry, dominated by contractors using concrete technologies Technological regime in the traditional dwelling construction innovation system opposed technological regime in the sub-innovation system of dwelling construction with the innovative bamboo technology No outward orientation in NBP actor network A general lack of knowledge and information about the new technology outside NBP network Disappearance of the tight sub-network with supporting actors providing financial means and support after dismantling of NBP in 1995. Due to this, the bamboo technology lost its preferential position of being more or less protected by governmental and financing agencies
Micro-level actor actions	Actor relations limited to NBP project actors The NBP management, acting as niche leader did not succeed in establishing a regime shift

The National Bamboo Project activities were not continued after a new period of administration in 1995 but taken over by a private foundation (FUNBAMBU). After the dismantling of the NBP group of actors, the traditional professional practices won over the use of the innovative bamboo technology. This organisation has to compete with the bamboo technology in the open market of dwelling construction which is dominated by contractors using concrete technologies.

Lessons learnt from the case study in the dwelling construction industry in Costa Rica are in line with theories and evidence in other industries, as discussed in previous sections. These indicate that a number of mechanisms that are important to ease the diffusion and implementation of innovative technologies should be put in place: (a) formation and strengthening of networks; (b) bringing about changes in the technological regime (1) by voicing and shaping of expectations about the new technologies and knowledge; and (2) by active technology and knowledge exchange amongst the actors in the innovation system about design and engineering specifications, user characteristics and their requirements, environmental issues, industrial development options, government policies, regulatory framework and governmental role concerning incentives for diffusion and implementation (Schot and Rip, 1996).

Thus, to manage processes of innovation and technology flows in order to successfully diffuse and implement innovative technologies; and to fully benefit from their technical and social advantages in the dwelling construction sector, the first and most obvious step to be taken is to gain full insight and understanding of the features of the innovation system: the roles and functional relations of the actors in the actor network; the prevailing technological regime; and the existing and competing technologies.

CONCLUSION

The fact that due to their complexity, the topics of innovation and diffusion in general and in construction in particular, are not yet fully understood induced us to engage upon this exploratory and descriptive research, in order to be able to answer questions concerning who, what, where, when and how regarding the diffusion of innovative technologies. After careful investigation of various approaches to analyse innovation and diffusion of innovative technologies, we identified the innovation system theories based on an operational framework which we developed to carry out this type of research. The authors are aware that exploratory and descriptive research have a basic weakness in their inability to specify actual relationships between the variables. However, the analyses result in a qualitative factual, accurate and systematic description of the situation. This offers opportunities to gather a better in-depth understanding of the reasons (who, why and how) behind human behaviour and decision making regarding the diffusion and acceptation of innovative technologies. The analyses enabled us to identify a pattern of promoting and constraining factors, which have an impact on the diffusion of innovative technologies. The factors could be traced back in the features of a prevailing innovation system and are in line with those found by other scholars.

As such, we conclude that analyses drawing on the innovation system theories are useful. The theoretical framework is generic, and thus not only applicable in developing countries. The results of the analyses may facilitate the management of innovation and technology flows for the benefit of more balanced construction industry development.

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