
INTERDEPENDENT SUSTAINABLE INNOVATION PROCESSES AND SYSTEMS IN DUTCH RESIDENTIAL BUILDING

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ABSTRACT

This paper explores and explains the relationship between interorganizational sustainable innovation processes and the elements of a national sustainable innovation system in building. The literature proposes that this relationship is characterized by mutual reinforcement. This paper integrates the interorganizational innovation process- and the national innovation systems-approach into a new model. A case research project, that covers a sixteen-year period of sustainable innovations in the Dutch residential building industry, investigates the interplay between process- and systematic sustainable innovation within the structure of the model. The research project indicates, illustrates, and explains how interorganizational sustainable innovation processes and a national sustainable innovation system in building co-develop in an interactive and mutually reinforcing process. In this process, the national system for sustainable innovation in building provides the structure in which the interorganizational sustainable innovative building processes develop. Simultaneously, the interorganizational sustainable innovative building processes stimulate the development of a national system of sustainable building innovation.

KEYWORDS

construction, ecology, ecological, ecologically, environment, environmentally, green, sustainability

1. INTRODUCTION

Building activities have a substantial impact on the environment. Building projects use finite natural materials and energy resources, change the environmental structuring, and produce large amounts of construction and demolition waste. In society, politics, and the building industry the awareness of a need for green, sustainable, environmentally conscious building processes and systems is growing. In the coming years, building needs to improve its sustainability when it wants to contribute to the greening of its industrial processes and systems. This paper's topic is the greening of both building processes and industrial building systems. It studies how the green building processes and systems in and between organizations in the building industry are organized. It aims to provide a first in-depth exploration of the relationship between cooperative green innovation processes and the elements of a national green innovation system. It searches for answers to the question of how cooperative green innovation processes and a national green

innovation system contribute to, and reinforce each other. For this purpose the sustainable building concept is used. This concept can be defined as all building activities that aim to contribute to environmental issues such as climate change, acid rain, the soil drying out, loss of biodiversity, changes in natural and materials cycles, and the exhaustion of finite materials and energy resources.

The paper is in six sections. This first section presents the central research theme. The second section reviews the literature on cooperative innovation processes and national systems of joint innovation. In the literature these two topics are addressed under the general terms 'interorganizational innovation processes' and 'national innovation systems'. The section develops a theory based model and three literature-based propositions that structure and direct an empirical study. The third section presents the design of an empirical case research project, covering a sixteen-year period of sustainable innovation in the Dutch residential building-industry. The fourth

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section describes the empirical research results within the boundaries of the theoretical model. It explores and explains the relationship between interorganizational sustainable innovation processes and the national system of sustainable innovation in Dutch building. The fifth section discusses the findings by means of an elaboration on the propositions, and a comparison of the empirical outcomes with the literature review. Finally, the sixth section ends with the main conclusions of the research project.

The organization of sustainable innovative processes and systems in an industry has not been the subject of in-depth study before. Research often tends to focus either on interorganizational innovation processes (Grandori and Soda, 1995; Elg and Johansson, 1997; Oliver and Ebers, 1998) or on national innovation systems (Freeman, 1995; 2002), and some recent research focuses on the relationship between the two concepts (Muller and Zenker, 2001; Sigurdson and Cheng, 2001; Lundvall *et al.*, 2002). The literature suggests, but does not empirically prove that there is a relationship of mutual reinforcement between interorganizational innovation processes and a national innovation system. This paper builds upon this suggestion and applies the two streams in the literature to investigate the interplay between interorganizational *sustainable* innovation processes and a national system of *sustainable* innovation. To researchers the paper provides a first in-depth investigation of this relationship. To practitioners it gives insights in the organization of the cooperative sustainable innovation process and system.

2. INTERORGANIZATIONAL INNOVATION PROCESSES AND NATIONAL INNOVATION SYSTEMS

Interorganizational innovation processes and national innovation systems are fields of interest that receive considerable attention in the literature. This section reviews the literature on interorganizational innovation processes and national innovation systems. Successively, it presents five models of interorganizational innovation processes, and three descriptions of the basic elements of a national innovation system. It ends with three propositions, derived from the literature, which focus on the relationship between interorganizational innovation processes and the elements of a national innovation system.

Interorganizational innovation processes

The interorganizational innovation process is an important research subject in the literature (Ring and Van de Ven, 1994; Shan *et al.*, 1994; Grandori and Soda, 1995; Powell *et al.*, 1996; Goes and Park, 1997; Chiesa and Manzini, 1998; Stuart, 2000; Baumol, 2001). A collection of sources in the literature divides interorganizational innovation processes into several stages (Kreiner and Schultz, 1993; Ring and Van de Ven, 1994; George and Farris, 1999; Bossink, 2002a; Fisher and Varga, 2002). This sub-section successively describes these five stage-models of interorganizational innovation processes.

Kreiner and Schultz (1993) distinguish three stages in the interorganizational innovation process: (1) discovering opportunities, (2) exploring possibilities, and (3) consummating collaboration. In the discovery-stage, organizations discover collaborative opportunities with other organizations. In the exploration-stage, they explore these opportunities, and translate them into concrete interorganizational innovation-projects. In the consummation-stage, they develop innovation plans, and realize them.

Ring and Van de Ven (1994) describe a three-stage model of interorganizational cooperation: (1) negotiations, (2) commitments, and (3) executions. In the negotiation-stage, organizations discuss the possible terms and procedures of a potential relationship. In the commitments-stage, they reach an agreement on the obligations and rules of the cooperation. In the execution-stage, they carry out the agreements. Organizations that complete the last activities in the execution-stage often enter the negotiation-stage for a second, third, fourth time, and so on. The organizations continuously assess the efficiency, and equity of all three stages. The outcomes of these assessments influence their willingness to participate in new cooperation-cycles.

George and Farris (1999) develop a four-stage model of the development of cooperative innovation processes: (1) recognition, (2) research, (3) relationship set-up, and (4) ramp-up. In the recognition-stage, organizations recognize the need of an alliance. In the research stage, they investigate the prospects of alliances with several other organizations. In the relationship-stage, they discuss and develop a collaboration-plan. Finally, in the ramp-up-stage, they realize this plan. George and Farris also

define a fifth stage, which is beyond the vulnerabilities of the first four stages: (5) ongoing management. In this post-cooperative stage, the partnering organizations dismantle the alliance, and integrate the remaining activities in their own organizational structure.

Bossink (2002a) discusses a four-stage model of interorganizational innovation processes: (1) autonomous strategy, (2) cooperative strategy, (3) organization for co-innovation, and (4) innovation-realization. In the autonomous strategy-stage, organizations develop and market their innovations independently. In the cooperative strategy-stage, they explore the possibilities to innovate with other organizations. In the organization-stage, the organizations create a joint venture for the development of the innovations. In the realization-stage, the joint venture produces and markets these innovations.

Fisher and Varga (2002) present a two-stage model of interorganizational innovation processes: (1) the pre-competitive stage, and (2) the competitive stage. In the pre-competitive stage, organizations exchange information, jointly identify new ideas, and conduct collaborative R&D. In the competitive stage, they develop a prototype, start pilot projects, and introduce their new products on the market.

National innovation systems

The national innovation system is a research subject that also receives considerable attention in the literature (Lundvall, 1992; Freeman, 1995; Laursen, 1996; Senker, 1996; Mowery, 1998; Davenport and Bibby, 1999; Arocena and Sutz, 2000; Etzkowitz and Leydesdorff, 2000; Park and Park, 2003; Kaiser and Prange, 2004). Three sources in the literature explicitly distinguish the basic elements of a national innovation system (Bartholomew, 1997; Sigurdson and Cheng, 2001; Lundvall *et al.*, 2002). This sub-section successively presents these three sources' descriptions of the basic elements of a national innovation system.

According to Bartholomew (1997), the four basic elements of a national innovation system are the government, research institutions, educational institutions, and the industrial firms. Research institutions and industrial firms are the centres of the system, and the government and educational institutions strengthen their function. The centres of the system develop the knowledge that is needed to innovate.

They share their knowledge in a cooperative innovation process. International contacts and working relations with foreign counterparts support the stock of knowledge in the research institutions, i.e. the first centre of the national innovation system. Another factor that contributes to the stock of knowledge is the national funding of basic research. A third factor, influencing the stock of knowledge of this centre of the system, is the national tradition of scientific education. The body of knowledge in the second centre of the national innovation system: industrial firms, is supported by the accumulation of technological knowledge in sectors that are related. Another factor that contributes to the knowledge reservoir in industrial firms is the cooperation with other organizations in R&D-projects. A third factor, supporting the stock of knowledge in this centre of the national innovation system, is the utilization of foreign technology. Several factors stimulate the flow of knowledge between the two centres of the national innovation system. A first factor, stimulating this knowledge-flow, is the commercial orientation of research institutions and their collaboration with industrial firms. Another factor is the mobility of labour in the country. A third factor is the willingness of the venture capitalists to invest in innovative public-private partnerships. Another factor is a government that actively stimulates knowledge exchange.

According to Sigurdson and Cheng (2001), a national innovation system consists of two basic elements: institutions and companies. National innovation-policies and corporate innovation-policies support the institutions and companies. The nation's institutions develop a national innovation-policy, which induces research, invention, development, and adoption of new technologies by the government, institutions, and firms. The nation's firms develop corporate innovation-policies, which govern the invention, development, and adoption of new technologies by firms. Both policies stimulate the development of a national innovation system. A national innovation system consists of several components. A first set of components supports the innovativeness of the government, institutions, and firms as a whole, and on a national scale. This set consists of a national: (1) higher education-policy, (2) R&D-infrastructure, and (3) policy on industrial development, trade, investment, and competition. A second set of components

stimulates the innovativeness of a nation's commercial firms on a corporate level. The set consists of the firms': (1) innovative capability and innovation strategy, (2) R&D-structure, (3) arrangements for advanced learning and access to newly developed knowledge and technology, (4) association with the public sector and networking ability, and (5) management of intellectual property rights. A third set of components links the first and second set of components into a coherent national innovation system. This third set consists of: (1) governmental and institutional arrangements, (2) the firms' influence on the governmental policy and on the institutional decision-making processes, and (3) strong cooperative links of firms with counterparts abroad.

According to Lundvall *et al.* (2002), a national innovation system consists of three basic elements: institutions, users, and producers. Lundvall *et al.* (2002) synthesize the concept of a national innovation system into four dynamic forces. These dynamic forces represent the interaction processes between the elements of a national innovation system. The first dynamic force is the development of new technology by interacting users and producers. The second dynamic force is the stimulating role of the home market for the national firm's economic specialization and autonomy. The third dynamic force consists of the coordination-, cooperation-, and interactive learning-processes between agents of the institutions, users, and producers in the national innovation system. The fourth dynamic force is the existence of nationally organized institutions, which determines the rate and directions of nation-wide innovative activities.

Propositions

As mentioned in the introduction, the literature suggests that there is a relationship of mutual reinforcement between interorganizational innovation processes and national innovation systems. This subsection presents three propositions that concentrate on the relationship between interorganizational *sustainable* innovation processes and the elements of a national system of *sustainable* innovation.

The sources in the literature argue that interorganizational innovation processes stimulate the development of innovations by clusters of organizations (Kreiner and Schultz, 1993; Ring and Van de Ven, 1994; George and Farris, 1999; Bossink, 2002a;

Fisher and Varga, 2002), and that several of these clusters together can form a national innovation system (Bartholomew, 1997; Sigurdson and Cheng, 2001; Lundvall *et al.*, 2002). This leads to the first proposition.

Proposition 1: Interorganizational sustainable innovation processes contribute to the development of a national sustainable innovation system.

Sources in the literature not only argue that the interorganizational innovation processes can contribute to the development of a national innovation system. They also argue that the national innovation system has a contributory effect on the interorganizational innovation processes between the organizations in the system. They argue that a national innovation system is the infrastructure that enables and stimulates the innovative activities by the clusters of organizations (Bartholomew, 1997; Sigurdson and Cheng, 2001; Lundvall *et al.*, 2002). This leads to the second proposition.

Proposition 2: A national sustainable innovation system contributes to the development of interorganizational sustainable innovation processes.

A third proposition stems from the first two propositions. When (1) interorganizational sustainable innovation processes contribute to the development of a national sustainable innovation system, and (2) a national sustainable innovation system contributes to the development of interorganizational sustainable innovation processes, then (3) this indicates that they have a mutually reinforcing relationship. This leads to the third proposition:

Proposition 3: Interorganizational sustainable innovation processes and a national sustainable innovation system have a mutually reinforcing relationship.

3. RESEARCH DESIGN AND METHODS

A research project in the Dutch residential building industry explored and explained the relationship between interorganizational sustainable innovation processes and a national system of sustainable innovation. This section presents the methodology, design, and methods of the project. It starts with the method-

ological framework of the study. It visualizes the propositions, and translates them into a research model. The section proceeds with a description of the industry in which the empirical research is situated. It continues with an outline of the research method, and data collection methods used in the empirical research, and ends with an outline of the method with which the empirical research results were analyzed.

Borch and Arthur's (1995) model for research in complex networks of cooperating organizations was the basis of the study's methodology. The model facilitated the exploration and analysis of strategies, tactics and operations by co-operating and co-innovating firms, and enabled a structured approach to identify, describe and understand the dynamics of cooperative sustainable innovation systems and processes in organizational networks. In Borch and Arthur's (1995) model, the first step is to develop a network research framework, and to describe the basic problems and questions. The second step is to develop a research design, and select real-life cases to study the basic problems and questions in their empirical context. The third step is to collect empirical data by means of documentary study, interviews, observations, and real-time studies. The fourth step of the methodology is to analyse the data. This data-analysis stage develops concepts, and categorizes these concepts into a description and analysis of the cases.

According to the first step of Borch and Arthur's framework, the propositions were translated into a research framework. The research framework in Figure 1 visualizes the relations as suggested by the propositions.

The small box in the figure visualizes a set of interorganizational sustainable innovation processes.

The large box visualizes a national sustainable innovation system. The small box is part of the large box, which means that interorganizational sustainable innovation processes are part of a national sustainable innovation system. The arrow with number one symbolizes the first proposition: interorganizational sustainable innovation processes contribute to the development of the elements of a national sustainable innovation system. The arrow with number two symbolizes the second proposition: the elements of a national sustainable innovation system contribute to the development of interorganizational sustainable innovation processes. The arrows with number three symbolize the third proposition: interorganizational sustainable innovation processes and the elements of a national sustainable innovation system are mutually reinforcing.

According to the second step in the methodology, a research design was developed to conduct empirical research, and to select a case to be the subject of the study. The empirical research was carried out in the Dutch residential building industry. Organizations in the building industry were used to work in interorganizational innovation projects (Tatum, 1989; Bresnen and Marshall, 2000; Gann, 2000; Miozzo and Dewick, 2004), and the Dutch residential building industry actively innovated in the field of sustainability (Kibert, 1994; Silvester, 1996; Van Hal, 2000; De Jonge, 2005). The research project aimed to develop a first in-depth and analytically valid descriptive model for the relationship between interorganizational sustainable building innovation processes and a national system of sustainable building innovation. For this reason, the research project had a qualitative and exploratory nature. It studied the interorganizational sustainable innovation processes

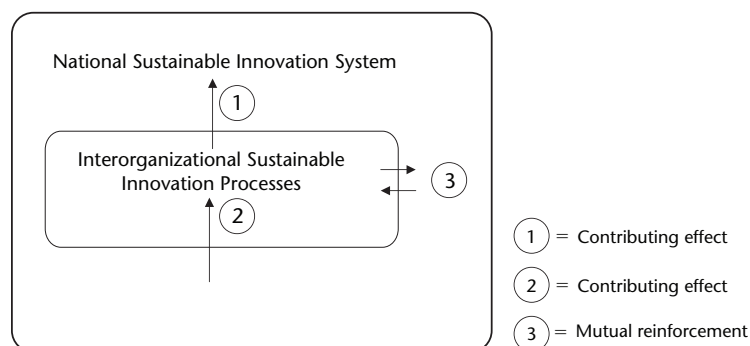


FIGURE 1. Research framework visualizing the propositions.

and the national sustainable innovation system in one of its actual contexts: the Dutch residential building industry (Creswell, 2003).

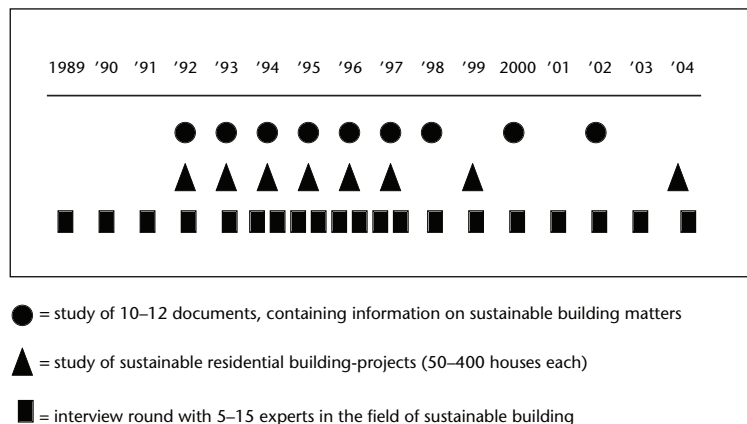
According to the third step in the methodology, the data collection stage in the research project used the case research method to develop a thorough outline of the interorganizational sustainable innovation processes, a national sustainable innovation system, and their relationship (Creswell, 2003; Yin, 2004). The case study covered a sixteen-year period in the Dutch residential building industry: from 1989 to 2004. Throughout this whole period, it collected information on the industry's sustainable interorganizational innovation processes, and national sustainable innovation system. The case study consisted of three distinctive research methods: expert-interviews, building project studies and document-analysis (Creswell, 2003). It interviewed eighty-three experts, observed eight building projects, and studied three-hundred-and-thirty-three documents. Figure 2 visualizes the activities during the research period.

The expert-interviews and document-studies developed a general overview of the Dutch residential building industry's interorganizational sustainable innovation processes and national sustainable innovation system. The project studies developed an in-depth insight. The expert-interviews and document-studies verified these insights. This methodological triangulation, i.e. the combination of several research methods that explored, double- and triple checked the findings in the empirical situation, contributed to the credibility of the research outcomes (Thomas, 2006). The project interviewed twenty-

nine commercial project-managers, twenty-one architects, and thirty-three institutional project-managers. It also studied eight building projects for housing estates of fifty to four-hundred houses each. Each project-study reviewed the outcomes of the design- and realization-processes, interviewed the representatives of the key-participants, and reviewed the project evaluation-reports. Documents that were gathered and studied are hundred-and-forty-two papers in professional building-journals, seven national environmental policy plans, sixty project evaluation-reports, fifty-five agreements and contracts, thirty-three drawings and design-documents, twenty-four information-brochures, seven project-plans, and five project-schedules. This data triangulation, i.e. the multiple data sources that were used to search for empirical patterns supported by all sources, contributed to the confirmability of the research results (Thomas, 2006).

According to the fourth step in Borch and Arthur's (1995) methodology, data analysis structured and explained the research outcomes. The three propositions were theory-based predictions of the patterns to trace in the empirical research. The analysis-stage of the research project compared the traced empirical patterns with the patterns predicted by the propositions. Additionally, it compared the case research project's findings with the findings that were found in the literature review. This theoretical triangulation, i.e. several complementary theoretical sources were used to analyze an empirical situation, contributed to the transferability of the research results to other contexts (Thomas, 2006).

FIGURE 2. Activities during the research period.



4. SUSTAINABLE INNOVATION IN THE DUTCH RESIDENTIAL BUILDING INDUSTRY

The research project studied the relationship between interorganizational sustainable innovation processes and the elements of a national sustainable innovation system in the Dutch residential building industry. This section presents results of the study that were confirmed by all data sources. The organization of the research outcomes is structured with the topics that were identified in the literature review, and the presented research outcomes refer to the basic data source that produced this finding. The section starts with a description of the Dutch residential building industry's interorganizational sustainable innovation processes. It continues with an overview of the industry's pillars of the national sustainable innovation system. Finally, it summarizes the impact of these sustainable innovation activities on the industry.

Interorganizational sustainable innovation processes

The building projects showed that clients, architects, consultants, and builders developed, designed, and built housing estates in projects, and worked with different partners in various projects. The interorganizational sustainable innovation processes in the Dutch residential building industry were cyclic. When an interorganizational sustainable innovation trajectory ended, the innovating parties often started all over again, and participated in new trajectories. The interorganizational sustainable innovation cycles that were distinguished in Dutch residential building consisted of eight successive stages. Organizations that completed the eighth stage, re-entered the first stage, and had the ability to participate in a new cycle with other partners. The building projects that were studied indicated that the duration of these cycles varied from two to five years. Institutions and firms that joined them, participated in several cycles at the same time, and joined new cycles when other cycles ended. The subsequent description is based on the project studies and provides a description and overview (Table 1) of the identified eight stages and its characteristics in most of the interorganizational sustainable innovation cycles.

1. Autonomy: The projects showed that in the first stage, institutions and firms operated independently.

The interviewed experts for example emphasized that the government and its institutions conducted research projects to develop new energy-efficient applications. Commercial firms adopted high-efficiency heating-systems and new insulating material in their products- and services-portfolio (Buis *et al.*, 2000). The experts stated that the government and its institutions promoted the newly developed environmental innovations. Firms built a green image with their sustainable products and services. The government and its institutions had funding-programs for research and development of new green technology. Firms adopted new sustainable products and services to serve or create new market demands (Bossink, 2002b).

2. Networking: The projects showed that in the second stage, institutions and firms got or kept in contact with organizations in their network. The government and its institutions for example wanted to experiment with new solar cells and vegetation-roofs in commercial building projects (Buis *et al.*, 2000). Some firms joined these experiments. The public institutions located their R&D-activities in energy-efficiency and sustainable materials in several organizations. The government forced these organizations to cooperate with new governmental laws, regulations, and policy plans (Bossink, 2002b). The interviews with the experts indicated that this resulted in the development of coherent packages of sustainable innovations. Firms met future counterparts on fairs, trades, and meetings all over the country.

3. Exploration: The project studies exemplified that in the third stage, institutions and firms explored the opportunities to innovate with each other. The government and its institutions offered subsidies for firms' participation in experiments and demonstration projects (Bossink, 2002b). The expert interviews revealed that firms wanted these extra contributions to cover their additional costs. The project studies indicated that the government and its institutions had the money and knowledge to develop new sustainable technology. They wanted to work with firms to experiment and explore the practical implications. Most firms lacked money, and lacked knowledge of environmental technology. The interviewed experts stated that to work with public R&D-centres enabled them to obtain free knowledge and competencies. The projects studies showed that the government, institutions, and firms had small databases with firms they

TABLE 1. The interorganizational innovation processes of sustainable building.

Stage	Patterns of Sustainable Building Innovation
1. Autonomy	Organizations: <ul style="list-style-type: none"> • innovated autonomously in sustainability, • managed their sustainable innovation portfolio, and • protected their sustainable innovations.
2. Networking	Organizations: <ul style="list-style-type: none"> • chose or were forced to innovate in sustainability, • preferred to work with well-known partners, and • realized an influential position in the innovative network.
3. Exploration	Organizations: <ul style="list-style-type: none"> • explored the costs and revenues of cooperation, • determined which expertise is needed, and • developed a cooperative portfolio.
4. Formation	Organizations: <ul style="list-style-type: none"> • negotiated over the costs and incomes, • entered into contracts, and • developed innovation plans.
5. Organization	Organizations: <ul style="list-style-type: none"> • established a joint organization, • established control bodies, and • developed an architectural blueprint.
6. Planning	Organizations: <ul style="list-style-type: none"> • allocated expertise, • facilitated cooperation and communication, and • started sustainable innovation development.
7. Co-innovation	Organizations: <ul style="list-style-type: none"> • coordinated sustainable innovation realization, • renegotiated over the costs and incomes, and • sold to the market and met profitability targets.
8. Dismantling	Organizations: <ul style="list-style-type: none"> • dismantled the joint organization.

successfully worked with in the past and wanted to work with in the future.

4. Formation: The project studies exemplified that in the fourth stage, institutions and firms agreed to innovate together. The government and its institutions presented the innovative programs and projects they successfully completed in the past. Firms did the same (Bossink, 2002a). The interviewed experts indicated that they stressed their capability to absorb the new knowledge. Institutions and firms preferred to work with partners they worked with before. The government and its institutions promised to deliver the new environmental knowledge that was needed.

Firms promised to absorb the new environmental knowledge and used it in the projects. The document study taught that the institutions and firms signed contracts. In these contracts, the institutions promised to sell the ground to the commercial firms when the project was completed. In return, the firms promised to work with energy-efficient technology and sustainable building materials.

5. Organization: The studied projects showed that in the fifth stage, institutions and firms created a joint venture. They translated the interorganizational approach, in which the organizations concentrated on cooperation possibilities, into a multifirm approach,

in which they cooperated. The contracts they signed became this joint venture's linking device (Bossink, 2002a). A second characteristic that was revealed by the project studies is that public and private parties established governance bodies. Agents of the government and its institutions controlled the application of energy-efficient technology and sustainable building materials in the joint venture. Agents of the commercial firms controlled the profitability of their share in the joint venture. The government, its institutions, and the firms in the joint venture developed sustainable town-and-country-plans, and drew sustainable houses (Van Hal, 2000).

6. Planning: The project studies showed that in the sixth stage, institutions and firms prepared to realize the joint venture's innovation plan. The government and its institutions appointed their representatives. They were responsible for the management and control of the energy-efficiency of the building project, and for the use of sustainable materials. The firms also appointed representatives. They were responsible for the management, control, and efficiency of the building project (Bossink, 2004a). The document study showed that the governmental and institutional representatives used checklists and scoring-methods to assess the environmental scores of the project. Firms used project-management methods to manage the building processes in the project. They used the governmental and institutional checklists and scoring-methods to decide which, and how much sustainable innovations they had to realize (Jansen, 2001). The government and its institutions defined the bottom-line of the innovation-score of the housing estates they built. Firms defined bottom-line-milestones and -deliverables in their project-management.

7. Co-innovation: The project studies indicated that in the seventh stage, the joint venture realized the innovation plan. Firms realized the planned deliverables, according to their time-schedule (Bossink, 2002c). The studied documents showed that the government and its institutions' national knowledge- and information-centres promoted the new housing estates. The documents showed that firms started advertising. They executed campaigns to sell their houses. The government and its institutions agreed with an environmental score higher than, or equal to their bottom-line. Firms cut costs to realize the project's profitability targets. They cancelled the

most expensive environmental innovations to stay within their budgets. At the end of this process, the joint venture sold the sustainable houses (Buis *et al.*, 2000).

8. Dismantling: The studied projects showed that in the eighth stage, the institutions and firms dismantled their joint venture. The interviewed experts stated that the government and its institutions absorbed the knowledge of the practical applicability of innovative design-options. The commercial firms absorbed the knowledge of the efficiency of the various environmental design-options (Van Hal, 2000). The document studies indicated that the government and its institutions integrated the knowledge of innovative design-options in future legislation, procedures, and plans (Bossink, 2002b). Firms that participated in the innovative projects labelled themselves as 'green companies'.

The National Sustainable Innovation System

The government, institutions, and commercial firms in the Dutch residential building industry innovated in a small national sustainable innovation system. This system consisted of eight pillars, which developed simultaneously. In the system, the governmental, institutional, scientific and commercial organizations developed innovative activities. This sub-section describes and gives an overview (Table 2) of the innovative activities of the organizations in each pillar.

1. Policy plans: The first pillar was a coherent set of environmental policy plans. In the research period, the Dutch government published four national environmental policy plans (Bossink, 2002b). The Dutch country was divided in several provinces, and each province was divided in municipalities. The document study showed that the provinces published provincial environmental policy plans, derived from the national plans. Moreover, the municipalities published municipal environmental policy plans, derived from the national- and the provincial policy plans. The government, the provinces, and municipalities defined environmental objectives. They also introduced environmental action plans. One of the plans' priorities was to improve the environmental performance of the residential building industry. The authorities confronted the industry with new environmental measures, and stimulated firms to cooperate. The four governmental plans contained more than 150

TABLE 2. Innovative activities of the organizations in the national sustainable innovation system.

Pillars of the national sustainable innovation system	Innovative activities of the organizations in each pillar of the national sustainable innovation system
1. Policy plans	Governmental organizations published environmental policy plans Institutional organizations executed environmental policy plans Scientific organizations participated in the execution of environmental policy plans Commercial organizations participated in the execution of environmental policy plans
2. Experiments	Governmental organizations funded experiments Institutional organizations organized experiments Scientific organizations participated in experiments Commercial organizations participated in experiments
3. Legislation	Governmental organizations activated and operated environmental laws Institutional organizations worked in accordance with environmental laws Scientific organizations worked in accordance with environmental laws Commercial organizations worked in accordance with environmental laws
4. R&D-projects	Governmental organizations supported R&D-projects Institutional organizations supported R&D-projects Scientific organizations executed R&D-projects Commercial organizations participated in R&D-projects
5. Demonstration projects	Governmental organizations funded demonstration projects Institutional organizations organized demonstration projects Scientific organizations participated in demonstration projects Commercial organization participated in demonstration projects
6. Design instruments	Governmental organizations supported the development of design instruments Institutional organizations worked with the design instruments Scientific organizations facilitated the development of the design instruments Commercial organizations developed and used the design instruments
7. Knowledge centres	Governmental organizations established the knowledge centres Institutional organizations participated in the knowledge centres Scientific organizations advised the knowledge centres Commercial organizations consulted the knowledge centres
8. Procedures	Governmental organizations developed and implemented the procedures Institutional organizations operated the procedures Scientific organizations facilitated the development of the procedures Commercial organizations worked in accordance with the procedures

national actions, and the government, one of their institutions, and some universities and commercial firms cooperatively executed them. As a result, they developed various new sustainable building materials, design concepts, and building concepts (Bossink, 2002b).

2. Experiments: The document study revealed that the second pillar was a series of experimental sustainable building projects in the country. In 1989, some private clients organized into an association,

which developed and built the first experimental sustainable housing estate. In the period that followed three symbolic housing estates were developed that were characterized by for example vegetation-roofs, and rainwater use for washing- and toilet facilities. In addition, a governmental institution started with similar experiments. Each year, it realized one or more experimental projects in the country (Buis *et al.*, 2000). The projects tested the possibilities of new sustainable ways of building, housing, and living. The

experiments illustrated the possibilities of sustainable residential building, and some of the private and institutional projects served as nationally recognized icons for green building. The experiments provided examples of innovative sustainable building methods. Innovations tested in these experiments were for example transparent rooms for passive use of solar energy, and the application of concrete with 20 percent rubble (Buis *et al.*, 2000).

3. Legislation: The document study also showed that the third pillar was a set of national laws that forced firms to work in accordance with environmental standards. Article 21 of the Dutch constitution dictated that the inhabitability of the country, and the protection and improvement of the environment was a governmental obligation. In return, the government stated that environmental care also was a shared and public-private responsibility. In 1989, the Dutch government operated eleven basic laws to activate and force firms to behave in an environmentally conscious way. The government restricted firms' air pollution- and soil pollution-levels. It restricted firms' possibilities to dump waste at landfills. New legislation obliged builders to separate and dump building waste in two to seven distinctive fractions. The legislative power of the government secured the specification and assurance of environmental standards (Bossink, 2004b).

4. R&D-projects: The document study showed that the fourth pillar was the set of projects to generate and develop new scientific environmental knowledge. In 1993, Dutch universities initiated fundamental research programs in sustainable construction. They qualified and quantified the effect of building activities on several environmental topics. These topics were climate change, acid rain, loss of biodiversity, changes in natural and material cycles, and the exhaustion of finite materials and energy resources. Universities also cooperated with architects and contractors to conduct applied research projects. Delft University of Technology for example initiated a project to develop a prototype for a sustainable city. Additionally, professors of Dutch universities started with instrumental research projects in the field. They combined consultancy activities with their scientific work, and applied science-based design- and assessment-instruments in commercial green building projects (Buis *et al.*, 2000). The fundamental, applied, and in-

strumental R&D-projects contributed to the development of the theoretical and practical knowledge in the field of sustainable building.

5. Demonstration projects: The project studies showed that the fifth pillar was a yearly growing set of environmental residential building projects. In 1993, several cities in the country developed and built their first sustainable housing estate. The government subsidized them, and labelled 33 projects as 'national demonstration projects' (Buis *et al.*, 2000). These acted as demonstrations on a provincial and municipal scale. In 1998, most of the big cities developed a sustainable building project. Most of the large and medium-sized municipalities developed and built one or more demonstration projects with remarkable sustainability scores (Buis *et al.*, 2000).

6. Design instruments: The project studies showed that the sixth pillar represented a collection of methods to assess the environmental impact of design- and build-decisions (De Jonge, 2005). In 1993, Dutch universities developed life cycle analysis (LCA-) methodologies for sustainable residential building. At the same time, several consultant firms developed checklists and scoring-methods. They derived these checklists and methods from the universities' LCA-methodologies (Jansen, 2001). The universities' research programs in LCA-methodologies for example provided insights into the embodied energy of materials. It also generated insights into the building materials' emissions of substances, related to for example climate change and acid rain. The consultants' checklists and scoring-methods clearly summarized the universities' applicable research results. Their instruments provided several options for design- and build-decisions. They quantified the environmental quality of these decisions. Architects and contractors in all demonstration projects in the Netherlands worked with these checklists and scoring methods (Bossink, 2002c).

7. Knowledge centres: The expert interviews revealed that the seventh pillar was the collection of centres with environmental expertise all over the country. In 1995, two provincial authorities started with a regional knowledge centre for sustainable residential building. In 1996, the Dutch government established a national knowledge centre for sustainable building. In the years that followed, various large and medium-sized cities established similar municipal

knowledge centres. The national centre stimulated sustainable building on a national scale. The provincial and municipal centres functioned as information desks for subsidies and information. Every year the national knowledge centre organized a national conference on sustainable building for representatives of governmental and commercial organizations.

8. Procedures: The document studies indicated that the eighth pillar was a set of national guidelines for sustainable residential building (Jansen, 2001). In 1997, the government introduced a national package of options for sustainable residential building. The concept behind this initiative was that participants in all residential building projects had to choose and realize a set of options from this package. The government also introduced a national energy-efficiency standard, which prescribed the energy-performance of houses. Additionally, the government introduced a nationally acknowledged scoring-procedure. This procedure enabled the assessment of a firm's contribution to the sustainability of a residential building project (Jansen, 2001). The national package, energy-efficiency standard, and the scoring procedures became directly and indirectly an integral part of the Dutch law. The government's initiatives assured an average sustainability standard in all residential building projects in the country.

Although the outcomes of the empirical case study show that significant activities were developed and considerable results were achieved, the impact remained relatively modest. In the country, 33 building projects received an official status of highly innovative in the field of sustainability. The majority of projects were less innovative or completely traditionally designed and built. In the studied period, the majority of firms in the building industry did not integrate sustainable innovations in their dwelling designs. The main reason was that the options were not economically feasible. Most of the firms waited for new legislation on sustainability to come, decided to do what they were expected to do, and not to exceed the governmental expectations. In addition to this, the case study also showed that when the program of 33 demonstration projects was completed in 2000, the government's and its institutions' active role as a initiator and facilitator of sustainable building projects ended. Its primary focus was to stimulate or force the

adoption of the national package for sustainable building and the energy efficiency standard by the 'average firm' in the industry. In the last period of the researched interval, from 2000 until 2004, the development of new sustainable building projects stagnated, the related interorganizational sustainable innovation processes decreased, and the development of the elements of the national sustainable innovation system declined.

5. THE RELATIONSHIP BETWEEN INTERORGANIZATIONAL SUSTAINABLE INNOVATION PROCESSES AND A NATIONAL SUSTAINABLE INNOVATION SYSTEM

This section compares the proposed literature-based relationship with the relationship that was found in the empirical research. Firstly, it describes the research findings' support for the propositions. Additionally, it discusses these research findings by means of a comparison with the literature on interorganizational innovation processes and national innovation systems.

Proposition 1: Interorganizational sustainable innovation processes contribute to the development of a national sustainable innovation system.

The empirical research supported the first proposition to a considerable degree. Interorganizational sustainable innovation processes contributed to the development of five (of the eight) pillars of the national innovation system for sustainable building. These five pillars were experiments, R&D-projects, demonstration projects, design instruments, and knowledge centres. Firstly, the project studies revealed that the government, one of its institutions, and twenty firms cooperatively realized the nation's experiments. Together, they went through cyclic interorganizational innovation processes, dedicated to projects experimenting with new sustainable building concepts and methods. Secondly, the document study showed that five scientific institutions and approximately hundred commercial firms realized the nation's fundamental, applied, and instrumental R&D-projects. Together, they went through interorganizational innovation cycles to develop new sustainable building knowledge, applications, and solutions. Thirdly, the document studies showed that the government, supported by its

institutions, cooperated with approximately hundred commercial firms to initiate and complete the nation's demonstration projects. Cooperatively and repeatedly, they went through interorganizational innovation processes to demonstrate the applicability of new sustainable building methods and technologies. In the fourth place, the projects studies revealed that four of the nation's scientific institutions and five commercial consultant's firms cooperated to develop sustainable design instruments. They went through interorganizational innovation cycles to develop and apply checklists and scoring methods that support the sustainable building process. Finally, the expert interviews showed that the Dutch government, most of the provinces, and some of the municipalities established knowledge centres with the help of many firms. All parties documented their experiences with interorganizational innovation processes, and transferred it to the knowledge centres.

Proposition 2: A national sustainable innovation system contributes to the development of interorganizational sustainable innovation processes.

The empirical research supported the second proposition. All eight pillars of the national sustainable innovation system contributed to the sustainability of the interorganizational innovation processes in the Dutch residential building industry. In the first place, the expert interviews showed that the environmental policy plans improved the environmental awareness of the nation's institutions and firms. It also influenced their willingness to cooperate in the interorganizational sustainable innovation processes in the country. In the second place, the project studies indicated that experimental projects served as benchmarks for the activities of participants in the regular interorganizational sustainable innovation processes in the country. In the third place, the studied documents showed that legislation forced all institutions and firms in the industry to work in accordance with national environmental laws, restrictions, and instructions. In the fourth place, the document studies exemplified that R&D-projects delivered new knowledge in the field of sustainable building and housing. The participants in the interorganizational sustainable innovation processes applied the newly developed scientific knowledge. Fifthly, the document studies showed that

the nation's demonstration projects illustrated the possibilities of sustainable building to all representatives of institutions and firms who initially were sceptical about the subject. The governmental demonstration program served as a benchmark for the activities of participants in the regular and less innovative interorganizational sustainable innovation processes in the country. Sixthly, the project studies showed that the development of design instruments had a stimulating effect on the sustainability of most of the interorganizational sustainable innovation processes in the country. All interorganizational sustainable innovation processes applied the outcomes of life cycle analysis, and used the science-based checklists and scoring methods to design and build sustainable housing estates. Seventhly, the interview rounds indicated that the various knowledge centres operated as environmental advisors and information-providers. The knowledge centres supported and facilitated national institutions and firms to take an active part in interorganizational sustainable innovation processes in the country. Finally, the document studies indicated that the procedures forced institutions and firms to apply a legally required number of sustainable methods, systems, and materials.

Proposition 3: Interorganizational sustainable innovation processes and a national sustainable innovation system have a mutually reinforcing relationship.

The empirical research supported the third proposition to a considerable degree. Interorganizational innovation processes and five (of the eight) pillars of the national innovation system in the Dutch residential building industry appeared to be mutually reinforcing. Firstly, the project studies indicated that interorganizational sustainable innovation processes and the experiments of the national innovation system for sustainable building were mutually stimulating. Experimental programs stimulated progressive interorganizational sustainable innovation processes in the country. In return, the outcomes of these interorganizational sustainable innovation processes stimulated the private parties and the governmental institutions to develop new and improved experimental programs. Secondly, the document studies indicated that the interorganizational sustainable innovation processes and the R&D-projects of the Dutch national innovation system for environmental

building were mutually reinforcing. The R&D-projects stimulated institutions and firms in the interorganizational environmental innovation processes to apply new science-based knowledge. In return, the application of this knowledge in the interorganizational innovation processes initiated new research questions and new R&D-projects. In the third place, the document studies showed that interorganizational sustainable innovation processes and the demonstration projects of the Dutch national innovation system in residential construction were mutually supporting. The Dutch demonstration program provided best practices. It stimulated institutions and firms in the industry to join interorganizational sustainable innovation processes, and to produce highly innovative housing estates. In return, the increasing environmental quality of these interorganizational sustainable innovation processes stimulated the creators of the demonstration programs to improve their programs. Fourthly, the project studies showed that the interorganizational sustainable innovation processes and the design instruments of the national innovation system were mutually reinforcing. The interorganizational sustainable innovation processes in the nation used the design instruments that were developed by consultants' firms. It improved their environmental performance. In return, the experiences with the application of these theory-based design instruments in the industry stimulated the consultants to improve their design tools. Finally, the expert interviews showed that the interorganizational sustainable innovation processes and the knowledge centres of the national sustainable innovation system were mutually reinforcing. The knowledge centres obtained the knowledge and expertise they needed from the participants in the interorganizational sustainable innovation processes. In return, the knowledge centres used this knowledge to stimulate the performance of participants in other interorganizational sustainable innovation processes in the residential building industry.

A Comparison of the Interorganizational Sustainable Innovation Processes with the Literature

All five models of interorganizational innovation processes in the literature pay attention to the trade-offs between the exploration of innovative options, and the exploitation of these options in terms of turnover, market share, and profits. The innovating organiza-

tions in the empirical research project also searched for a balance between exploration and exploitation. In the first four stages of the sustainable innovation process, they explored the joint innovation possibilities and potential. In the fifth until the eighth stage of the innovation cycle they developed, produced, and marketed the innovative sustainable options with a profit motive. Although the studied projects achieved considerable results in sustainable innovation, many options that were technologically possible were not applied because of conflicting economic motives of the participants in the projects. In the first four exploratory stages of the interorganizational sustainable innovation cycle the organizations primarily explored the economically feasible options, and applied these in the fifth, sixth, seventh and eighth exploitation stages of the interorganizational sustainable innovation cycle. The majority of options that were put aside were rejected for economical reasons.

Furthermore, the models in the literature suggest that the organizations that participate in the interorganizational innovation process try to find a balance between competition and cooperation. Fisher and Varga (2002), for example are very explicit. They label the two stages in the interorganizational innovation process as 'pre-competition' and 'competition'. The empirical research results confirm this. The organizations that were observed spent most of their time on negotiations over the optional conditions of joint innovation in the first four stages of the interorganizational sustainable innovation cycle. When the deal was closed, most of the times when the fourth stage of the sustainable innovation cycle ended, the competitive approach developed into a more cooperative one. Nevertheless, also in the fifth until the eighth process this cooperative approach had competitive elements. All members of the joint project realized that the cooperation would end, and that they had to be able to exploit their new competencies autonomously. They just applied sustainable innovations that were cost-neutral, or generated extra profits.

A Comparison of the National Sustainable Innovation System with the Literature

The system of sustainable innovation in the Dutch residential building industry partially functions as supposed in the literature. It also deviates from several basic assumptions in the literature.

According to Bartholomew (1997), research institutions and industrial firms are the centres of the national system of innovation, and the government and educational institutions strengthen them. The research project revealed that not the research institutions and industrial firms, but the government acted in the centre of the system. Some research institutions and a small group of specialized firms supported the government. They participated in the experiments, R&D- and demonstration projects. The majority of the firms in the industry was passive and did not cooperate. The movement that came into being was relatively small and an industry-wide movement did not develop. Bartholomew (1997) also states that in a productive national innovation system knowledge flows between research institutions and industrial firms. The research project did not trace such processes of knowledge flow between research institutions and the majority of commercial firms. The only flow of knowledge the research project found was the cooperation between some research centres and a small group of specialized firms. In these cases researchers transferred LCA-information to some consultants and architects. These consultants and architects translated this information into design instruments, and applied them in the sustainable building projects. The flow of knowledge from the small network of innovating organizations to the industry as a whole was not stimulated and facilitated, and the diffusion of the approach in the sustainable innovation processes and system to all the organizations in the industry was not systematically organized.

According to Sigurdson and Cheng (2001), national and corporate innovation policies support the innovative capability of institutions and companies. This support partially existed in the Dutch house building industry. National, provincial, and municipal sustainable innovation policies and action plans facilitated the governmental institutions. Although these policies and plans also aimed to stimulate commercial firms, this was not actually happening. Moreover, companies also did not develop and operate corporate sustainable innovation policies and plans of their own. Most of the commercial firms felt no need to innovate because of the absence of economical incentives to become sustainable.

Finally, according to Lundvall *et al.* (2002), the development of new technology by interacting users and producers is an important element of a national

system of innovation. In the Dutch case, most sustainable technologies, for example the design instruments, were developed, tested, and made by combinations of interacting universities, scientific research centres, consultants, architects, and builders. The scientific institutions developed the necessary knowledge. The architects and consultants translated the knowledge into applicable design methods. They used these methods while working with, and for construction companies. The research project did not find any other important element of the national innovation system-concept of Lundvall *et al.* (2002). Although the government created a small and experimental market for sustainable building projects, it did not create a large home market for sustainable building. The government also did not develop a nationwide direction for sustainable building. The knowledge centres had an informative function, but did not develop a long-term vision. The relatively small scale of the sustainability movement facilitated a successful small network of organizations that were innovating in sustainability, but the network remained small, did not grow, and even declined in the last years of the period that was researched.

6. CONCLUSION

This paper explored and explained the mutual reinforcing relationship between interorganizational sustainable innovation processes and the elements of a national sustainable innovation system in Dutch residential building. It integrated the interorganizational innovation process- and the national innovation system-approach into a new model. Within the structure of this model, a case research project that covered a sixteen-year period of sustainable innovations in the Dutch residential building industry investigated the interplay between sustainable process- and systematic innovation. An analysis of the research outcomes showed that a national sustainable innovation system provided the structure in which several interorganizational sustainable innovation processes developed, and that the interorganizational sustainable innovation processes contributed to the building of this national system of sustainable innovation. Additionally, the research showed that the national sustainable innovation system and the collection of interorganizational sustainable innovation processes was relatively small. It also indicated

that the sustainable innovations that were not cost-neutral or profitable—and most of them were not—were put aside by the participants.

The literature on the subject indicated that a conceptual research approach in which sustainable innovation processes and -systems were integrated could provide new insights into the interplay between interorganizational sustainable innovation processes and a national system of sustainable innovation (Muller and Zenker, 2001; Sigurdson and Cheng, 2001; Lundvall et al., 2002). This approach was adopted in the research design. The exemplary and in-depth case study project revealed that the government, institutions, and a small network of commercial organizations cooperatively succeeded to develop an interdependent collection of interorganizational sustainable innovation processes and pillars of a sustainable innovation system. Although this organizational network achieved considerable sustainable building results, the absence of sufficient economic incentives appeared to be an impediment to the development of the small innovative network into a larger movement.

The development of a research approach with a focus on both interorganizational sustainable innovation processes and national systems of sustainable innovation appeared to be a promising direction for research. It enabled the integration of both process- and systematic aspects of the development of a sustainable building industry. Analytically, the research methodology and approach can be useful for making an in-depth study of the interplay between sustainable innovation processes and -systems in building industries in various other countries. Further research can concentrate on the transferability of the research approach and findings to these contexts. Although the results indicated that a mutually stimulating relationship between sustainable innovation processes and a national sustainable innovation system exists, this finding can not be generalized to other contexts, neither analytically or statistically. The research provides a first in-depth description of the relationship. For analytical generalization replication of the study and its results is needed. For statistical generalization a quantitative research design is demanded. Further analytical research on the topic also needs to develop insights in the economic trade-offs of sustainable innovations, and the economic

and organizational aspects of the diffusion of sustainable innovations to the majority of the industry.

This research project argued that it is fruitful for organizations to participate in interorganizational sustainable innovative processes that are part of a national sustainable innovation system. It implicates that independent building organizations that want to innovate in sustainability have to become part of an interdependent network of cooperatively innovating governmental, institutional, scientific, and commercial organizations.

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