# Nature of innovation in the canadian construction industry

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# Nature of Innovation in the Canadian Construction Industry

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# Executive Summary

The review of innovation in construction suggests the following:

## Features of the Construction Industry

- It consists of assemblers of outputs of other industries.
- It is highly-fragmented and complex, with many stakeholder groups, and many small firms.
- Product, process, and systems innovations are all important.
- Buildings are different from products of other industries: they are large, immobile, costly, and very long-lasting.
- The most defining characteristic of the industry and its innovations is that they are project-based.

## What Drives Innovation?

- Market pull — the ability of contractors to win jobs, and the ability of developers to sell to customers — and the regulatory agencies are the most important sources of innovation. Technology push, although an important force through suppliers and government regulators, is probably less important than market pull.
- Prescriptive regulations promote the latest safety-related technology, but don't do much to assist innovation related to performance. Objective performance-based codes probably foster innovation.
- The commodity side of construction is driven by cost reduction innovations. To a lesser extent, innovations that reduce on-site time are also important.
- Individual innovators and project-based innovation are also important (e.g., to solve problems created by climate, site variations, need for immediate cost savings, or technical challenges).

## What Hinders Innovation?

- Financial and legal risks to stakeholders are the most important barriers to innovation.
- Most traditional procurement practices hinder innovation, especially "low bid" systems and overly-detailed procurement prescriptions.
- Too few stakeholders share in the innovation process—unless the technical and financial risk is shared among owners, designers, operators, and constructors (and possibly governments) innovation is stifled.
- Political and financial issues also hinder innovation for large government owners—political decisions need to be based on objective data that often don't exist; while the

frequent separation of capital and operating budgets eliminates consideration of life-cycle costs during procurement

- Prescriptive codes tend to inhibit innovation (other than any innovation inherent in a new code).
- It is difficult for innovators to capture benefits (there is little intellectual property, and the end-user rather than the innovator may capture performance benefits).
- Strong markets tend to inhibit innovation since "anything sells".

## What Types of Innovation are Most Readily Adopted?

- On the commodity side, cost-savings innovations are most easily adopted.
- On the decorative side, innovations that increase flexibility and creativity are valued.
- Performance innovations have not been of great interest to date for owners and end-users, with some exceptions on the government side (e.g., energy efficiency, ventilation).
- SMEs are most comfortable with small incremental innovations.
- Residential customers are more interested in "look and feel" than performance.
- Constructors are becoming more interested in performance as warranty spans increase.
- Process and product innovations are equally important; systems innovations are also important but probably in more restricted situations.

## Who are the Most Important Innovators, and Why?

- Large owners who are responsible for long-term performance and maintenance are important innovators—but public owners may be limited by political or procurement considerations, as well as the state of the market and the separation of capital and operating budgets.
- Public R&D organisations are important for understanding the physical basis of materials and methods, for providing innovation infrastructure support (e.g., testing) and for code and public-good research, mostly disseminated on system-wide basis. Thus they fill a "market failure" gap. However, they tend not to focus on other factors that inhibit innovation, or on indirect benefits to partners.
- Manufacturers and suppliers innovate with respect to new products.

## Nature of Innovation

- Most innovation is incremental and project-based.
- Building performance innovation has been slow.
- Innovative stakeholders (other than federal R&D agencies) are faced with two additional barriers not found in most other industries: (1) detailed procurement specifications; and (2) prescriptive codes and standards.

- There are some unusual gaps in information dissemination, especially among developers, owners, operators, and end-users. Overall there is reason to think that communication and feedback is poorer than in many other industries.
- There is little industry-wide strategic thinking regarding innovation.

## Implications for Thinking about Innovation

- The industry really is project-based. Accept this fact and design solutions around it. Possibly, study other project-based industries for "lessons learned".
- There needs to be more focus on why innovation is initiated, and why end-users need it.
- Much more attention is needed on factors that influence risk to innovators.
- Don't restrict thinking about innovation to formal research—much of the innovation in construction happens at a project level, carried out by non-scientists.
- Collaboration and cooperation among stakeholders is required to address the industry's strategic needs.

## Implications for Public Sector R&D Organisations

- Lack of technology isn't the problem—barriers to take-up of innovation are. Thus the overall goal of a public sector R&D organisation should be to find ways of creating effective technology transfer and remove these barriers, not just to carry out the scientific research that supports this goal.
- All the barriers to technology transfer should be explicitly considered in each research project carried out by public sector R&D agencies: e.g., risk to stakeholders in embracing the innovation, impact of procurement practices and financial and budgeting factors, provision of indirect benefits to partners, ways to improve capture of benefits, need for training and education, etc. There should be active investigation of ways to overcome these barriers through explicit research on the barriers themselves (especially risk, procurement practices, and objective performance-based codes and standards).
- Public sector organisations have an appropriate strategic and coordinating role, with the active collaborative participation of other stakeholders at all stages of the research program, possibly based on technology transfer models from other sectors.
- The goals of strategic planning should be to: (1) Identify market and stakeholder innovation needs; (2) Identify public policy needs; (3) Identify the R&D needs of government owners and operators; and (4) Address barriers and constraints to innovation.
- Process and systems research should be addressed, in addition to materials and products research.
- Careful planning needed to address the very wide range of stakeholder types, needs, and sophistication.

# 1. Introduction

## 1.1 Purpose of This Paper

The Institute for Research in Construction (IRC) carries out R&D to support its mission to provide Canada's construction industry with the best possible technology. This in turn is intended to support the National Research Council's mission to enhance the socio-economic well-being and competitiveness of Canada. In order for IRC to carry out its mission effectively, the nature of innovation within the construction industry must be understood. This paper discusses key features of innovation in the construction industry. In addition, some general models of the technical innovation process are discussed in order to consider their applicability to the construction sector.

The nature of the construction industry and the nature of innovation are large and complex topics. This paper is not intended to be comprehensive or definitive on either one—the literature on both is extensive and there exist many areas where knowledge is sketchy or there is controversy. Instead, this paper summarises key features of the construction industry, innovation models, and the relationship between them.

In order to prepare this paper, a literature review was undertaken, and various contacts within the industry were interviewed. The latter are found in the appendix, and included researchers, industrialised builders, designers, SMEs in residential and commercial building, product manufacturers, and heavy construction. Again neither the literature search nor the interviews were intended to be exhaustive.

## 1.2 Acknowledgements

This paper is based upon extensive thought by other parties and we would be remiss not to acknowledge them. Some of the people upon whose work the models in this paper are based include Steven J. Kline, David Gann, Vernon Ruttan, Howard Bernstein, Andrew Lemer, and George Seaden. Additional thanks are given to the respondents listed in Appendix A, without whom this study would have been impossible.

# 2. Innovation Models in General

Brief descriptions of some general innovation models are provided in order to consider their applicability to the construction industry. Some models describe how innovation occurs; others, why it occurs.

## 2.1 Linear Models

This model describes how research and innovation work together, and assumes an orderly flow over time of innovation:

- initial research leading to discovery of new knowledge, in turn leading to
- development of that new knowledge to market-ready stage, leading to
- production of the new/improved product, leading to
- marketing of the product.

Linear innovation chains are often explicitly or implicitly assumed to exist by reviewers of R&D programs, especially when attempts are made to measure impacts in terms of changes to private sector revenues (e.g., increased sales of new/improved products, licence fees, royalties, etc.). This type of model is also easily understood in cases where research leads to "direct benefits"—in ARA's definition, direct benefits are those where new or improved products are developed directly from application of the research results of a specific research project. However, linear models have a number of significant shortcomings:

- They assume that research and discovery initiate the exploitation process, and ignore the possibility that the reverse can be true—that problems of design, testing, production, distribution, or marketing can drive research.
- They ignore the contribution of the large existing knowledge base (consisting of the research literature, knowledge contained in professional and technical journals, knowledge held by practitioners in the field, etc.).
- They don't work very well in cases where research projects contribute indirectly to innovation or innovative capability. For example, they don't account for the increase in technical "know-how" that a firm may obtain from being associated with a research project, and which may later assist the firm in areas entirely disassociated from the original research project.
- They don't work well where there are innovations in process technology (how individual products are manufactured), or in systems technology (how different technologies are assembled into complex products).
- They don't work well where public good research is carried out, and market forces are not the primary driver.
- They don't discuss the research infrastructure that supports innovation in both the public and private sector.

## 2.2 Chain-Linked Models

The chain-linked model was developed by Kline[1] in order to address the shortcomings of the linear innovation model, and many investigators have suggested incremental changes ever since. It is the model currently used by the OECD[2]. Exhibit 2.1 shows the essence of Kline's model (but see the points below for some things left out). Most of Kline's examples assume that innovation is usually driven in response to problem-solving of either a technical or a financial nature, but otherwise the model mainly focuses on the "how" of innovation, not the "why". There are several key features of this model:

- Research is not the only initiating point for innovation. Instead, research may itself be initiated in response to problems in markets, design, testing, production, and distribution.
- The knowledge base and the research process can support all stages of the innovation process, instead of being limited to providing input to the invention or analytic design stage, as in the linear model.
- Carrying out research is not the normal response to a technical problem. Instead the existing knowledge base is used as the first resource by anyone who needs to innovate. Only if this base is insufficient will research be considered as an option.
- By implication of the point above, there are often long time lags between creating research results and exploiting those results.
- By implication of the reliance on existing knowledge, firms will often invest not just in research projects intended to develop specific products, but also primarily to be able to identify, acquire, and utilise information which is available from external sources[3], thus increasing their "absorptive capacity" to use the "codified knowledge" contained in available research and technical literature.
- There exist information feedback loops between the various stages of innovation (e.g., between the design stage and the production stage), between the distribution and marketing stage and all other stages, and between distribution and marketing and the research process. In fact, the model assumes that such feedback is required for innovation to proceed effectively. (Showing all the feedback loops makes the diagram needlessly complicated, but one can imagine them between all components of the diagram.)
- Because of the feedback loops, the concepts of "technology push" and "market pull" have little meaning.

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[1] Kline, Stephen J. (1985), *Innovation is not a linear process*, **Research Management**, Vol 28 No. 4, July-August 1985, pp 36-45.

[2] Organisation for Economic Cooperation and Development (1994), *National Systems of Innovation: General Conceptual Framework*, DSTI/STIP/TIP 94.4 (Paris)

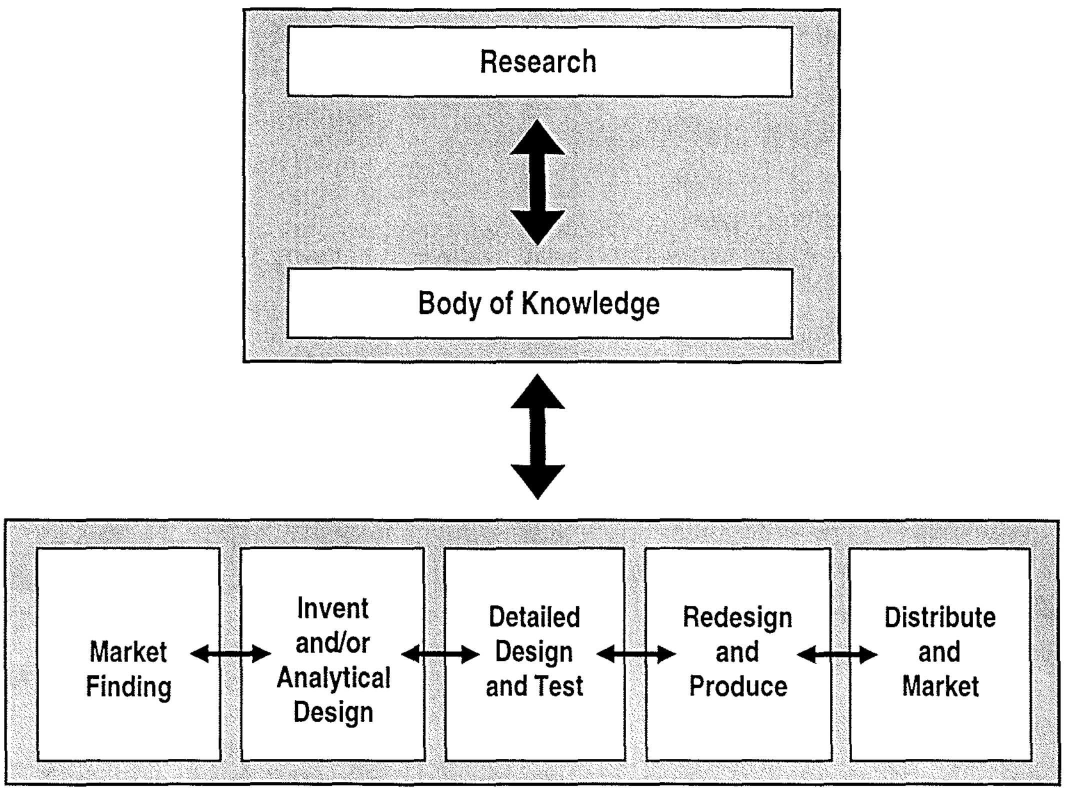
[3] See, e.g., *Internal Diffusion of Technology: The Case of Semi-Conductors*, (1971) Tilton, J.H., Brookings Institution, Washington DC,; and *Managing the Flow of Technology*, (1977) Allen, T.J., MIT Press, Cambridge University.

- The innovation and research processes do not only result in new or improved products. Innovations also result for systems design and production, and these innovations can be equally significant—indeed they make many modern products possible.

This model describes the market as a whole and the action of individual firms. Some researchers have also found that individual inventors play a significant role—in mature industries, they may play a greater role than static organizations.[4]

There are still some limitations to the chain-linked model, in particular in that the model focuses mainly on the direct benefits of research activities. Although indirect and system impacts of research activities can be inferred (these are discussed further below), they are not explicitly addressed.

**Exhibit 2.1: Chain-Linked Innovation Model**




Based on Kline (1985)

[4] Klein, Burton (1977), *Dynamic Economics*, Harvard University Press

## 2.3 Induced Innovation Model

The induced innovation model[5] tries to describe the reasons why innovation occurs. This is an economic model that only describes free-market, purely competitive responses to economic changes. This is the dominant model of innovation currently used by policy makers and commentators. It rests on the fundamental assumption that innovation occurs because it appears profitable to undertake the costs.

In induced innovation models, theorists first assume that the market will tend to use the particular combination of technologies that provide the optimum (lowest cost) combination of product inputs (for buildings, inputs include the price of labour, materials, land, etc.) in order to produce a product with the required specifications (e.g., size, quality, durability, etc.). Innovation occurs in response to a change in the price of a given product input. For example, if the price of concrete goes up, the response will be to find ways of making concrete less expensive, to use less of it, to pour it more efficiently, and so on. These economic market pressures will tend to induce innovations that reduce the costs of the most expensive (scarcest, in economic terminology) building inputs.

To do so efficiently, the market must be guided by price signals in the market. Thus the model assumes that:

- Prices reflect real changes in the supply and demand of products, resources and factors of production. That is, there are no distortions caused by government subsidies, trade barriers, etc.
- Effective communication and interaction exists between input suppliers, the industries involved, final consumers, and the research institutions. For the model to work, the various parties must know the true (or approximately true) values and costs of the various inputs. If this is not the case, then inducement for innovation may not be created. For instance, if concrete manufacturers are faced with a large cost increase for power to their manufacturing plants, but for some reason do not pass this cost along to their customers, then there is no reason for innovation in the use of concrete.
- Innovations will not occur, or will not be disseminated, if the innovators cannot capture their benefits. At a project-specific level, if a contractor can effectively use less expensive concrete he will enjoy a cost savings that spurs innovation. There would, however, be no incentive for the contractor to tell anyone else about the new technique.

There are a number of significant problems associated with induced innovation models, however:

- They focus strictly on market pull—innovation occurs only in response to a change in input prices. Thus they don't work well for technology push—innovations that create

[5] For example, see Ruttan, Vernon W. (1966) *Induced Innovation, Evolutionary Theory and Path Dependence: Sources of Technical Change*, Unpublished paper presented at seminars at the International Institute of Applied Systems Analysis, The University of Minnesota Economic Development Center, and the Hong Kong University of Science and Technology. Internet reference http://192.100.189.39/cimmyt/workshops/ruttan.htm.

entirely new markets or which improve performance, either of which (perhaps) increases costs.

- Performance is not always captured in prices. This is especially true for public goods such as indoor air quality, and therefore there is no private sector incentive assumed to exist in these areas. By extension, the model does not address innovation done for reasons of social policy, that result from government intervention, or that result from other social forces other than free-market competition. Thus the actions of government to improve equity, or the drive to produce innovations that focus on energy efficiency, environmental impacts, indoor air quality, etc., are not well described. (Of course, if governments offer incentives to innovate in these areas, then innovations may occur.)
- It is unclear how the model predicts responses to changes in initial prices, versus long-term operating costs. (The latter might be assumed to be relatively unimportant if there is not a great deal of interest in them. Within the model this could be considered a failure to provide real information on prices.)
- The human element is missing, or at least human needs other than financial. For example, in the model innovators won't innovate for the sheer interest in it. The model predicts the response of the market overall, whereas many innovations occur because of the actions of specific individuals, some of whom may not respond to price signals (i.e., they may innovate even if they lose money as a result).
- The nature of technical and legal risks to individuals or firms engaged in innovation is not considered. In fact, the model does not discuss any transaction costs between parties, such as the costs of meeting regulatory requirements, testing, bidding, negotiations, enforcing contracts, etc. (There are models of transaction costs called "agency theory" that follow similar neo-classical economic arguments as does the induced innovation theory[6].)
- The links to research activities are not described, and there are no distinctions made between direct, indirect, and system research impacts.
- The direction of causation is unproved. For instance, does workplace mechanisation cause lower wages (as less skilled workers are required), or do high wages induce mechanisation? Both are probably true—this mutual feedback is consistent with chain-linked models.

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[6] E.g. Bromley, Daniel W. and Cocrhrane, Jeffrey A. *A Bargaining Framework for the Global Commons*, in Bromley, Daniel W. (Ed.) (1995) **The Handbook of Environmental Economics**, Blackwell, Cambridge, Mass. pp 300-303.

# 3. Innovation in the Construction Industry

## 3.1 Features of the Industry

> *[Construction] is such a huge, sprawling, and intricately multi-faceted set of activities, institutions, and individuals that even to use a single word like "industry" seems inappropriate*[7].

Unlike many other industries, the construction industry is characterised by a number of features that make it unique and that pose unique difficulties for innovation. Some of these include:

- The construction process consists of assembling the outputs of other industries, with the final product owned and operated by a variety of other stakeholders. The key players are:
  - Owners or developers initiate the construction process.
  - For the construction process, the key industries are: designers (including architects and engineers), manufacturers and suppliers (e.g., of products such as window assemblies, construction equipment and tools, and materials such as wood and steel studs), and constructors.
  - Once a building is constructed, another set of stakeholders come to the fore: owners, leasers, operators, and managers.
  - Finally, the "end-users" actually use the facility. These include private and commercial tenants, homeowners, businesses, utilities, and so on. For commercial and residential properties, the end-users are often different from the owners and/or developers who initiated the construction, and from the operators who run them.
- In the construction industry the relative need for process and systems types of innovation, versus the need for product innovations, may be higher than in many other industries. This is partially caused by the low profit margins in construction (which make cost saving innovations important), and partially by the lack of interest in many types of building performance features.
- Buildings are large, immobile, costly, and very long-lasting compared to the products of most other industries. As a result, they are difficult to build off-site, not especially sensitive to certain high-performance innovations (e.g., those that reduce weight), risky to innovate on, and represent large fixed assets for owners, respectively.
- It is a project-based industry, with substantial project-by-project and site-by-site variation.
- Many firms in the construction industry are small or very small, with limited financial and technical resources.

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[7] Bernstein, Harvey M., and Lemer, Andrew C. (1996), *Solving the Innovation Puzzle, Challenges Facing the U.S. Design and Construction Industry*, American Society of Civil Engineers, New York.

## 3.2 Overview of the Innovation Process in Construction

There are various ways of conceptualising the innovation process in construction. For discussion purposes we have divided the question into three parts:

1. What drives or hinders innovation?
2. Who innovates, and why?
3. How does the industry as a whole learn about innovations?

Each of these main issues is discussed further below. The sub-questions listed within each question are important in that they represent a distillation of literature in the field as to the main issues affecting innovation within construction. The discussion within each sub-question reflects opinions found in the literature, plus those of experts we contacted during this study. However, these discussions are intended to be illustrative rather than definitive: it was not possible within this study's time and budget constraints to do otherwise.

In general, while there are areas of consensus (e.g., most experts regard innovation levels as being low in this industry compared to many others), there are substantial areas of disagreement as well (e.g., there is less agreement about—or less understanding of—who does most of the innovation, or why). At the broadest level the most striking thing about construction is the complexity of this industry, its players, and its products. For any given question, one quickly learns that it is difficult to generalise because of this complexity. By extension, any program or process that attempts to change the innovative process must be very carefully thought out, and must fully consider the needs of each player, the interactions among them, the economic conditions, and legal implications.

Because of the complex answers to some of the issues discussed below, we have provided a short summary at the end of the more complicated sections.

## 3.3 What drives or hinders innovation?

### 3.3.1 What are the respective roles of technology "push", market "pull", and regulatory bodies?

#### *Technology push*

Technology push can have a significant role, especially if driven by one or more strongly enthusiastic people. For example, marketers for firms producing product innovations actively pursue sales opportunities for these new products. Since the industry is widely and correctly seen to be very conservative (for reasons discussed below), technology push can help overcome this natural resistance. Because of economic and financial reasons, technology push tends to come from larger firms, and because it's easier for suppliers and manufacturers to capture benefits of innovation, they tend to be more active than other stakeholders in "push" activities. However, successful "push" usually depends on some new market opportunity popping up, as when the need for quick repair to severe earthquake damage in Loma Prieta, California, stimulated use of carbon-fibre wrapping technology to repair damaged concrete columns.

In addition, recent thinking on technology push from research organisations suggests that it is difficult to effect technology transfer (especially from basic research) without strong involvement of users at all stages of the process, and especially during the research planning stages. In the most effective technology transfer programs[8], non-research stakeholders (including industry, government, and perhaps end-users) are strongly involved in the research program. Depending on the research agenda and the type of stakeholders represented, these external parties may be involved in one or more of the following ways:

- hold voting positions on the Board of Directors of the research organisation;
- help design the overall research program by identifying market or technical challenges that the program must respond to;
- help select individual research projects and decide on relative funding allocations among them;
- sit on internal committees (e.g., for intellectual property issues);
- engage in personnel transfer (including students and post-docs) back and forth between research laboratories and industry sites;
- help carry out the research (including making cash and in-kind contributions);
- engage in a variety of internal communications with researchers and other industry and/or government participants (e.g., workshops, annual general meetings, consortia) in order to obtain technology transfer; and
- ultimately benefit from direct, indirect, and system impacts of the research.

### *Market pull*

Market pull is implied by most neo-classical economic models and works well to describe innovations that are intended to reduce costs. However, the reason for innovation can be either to reduce costs (probably the most common reason for most innovations) or to generate increased revenues from new markets. Systems research to reduce the cost of complex structures is another good example of market pull. The small to medium-sized builders appear to be very responsive to market factors. For example, in residential housing the key question asked of any technical or design feature is, "Will this make a buy/not buy decision for a buyer?" Most industry observers believe that market pull is more important than technology push.

However, others would argue that neither technology push nor market pull are the key factor: take-up of new technology may depend on whether the innovation is reasonably compatible with existing industry procedures; innovations that only require incremental changes to techniques and knowledge are easier to adopt. (This is also consistent with "path dependence" in economic modelling of innovation—the use of innovations is constrained to some degree by needing to fit within the existing envelope of technologies, methods, infrastructure, and so forth.) In addition, push versus pull depends on whether one is talking about the project level or the industry level—at the project level innovation is often about solving site problems and there's little incentive (or

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[8] See, e.g., The ARA Consulting Group (January 1997) *Final Report Evaluation of the Networks of Centres of Excellence Program*, prepared for the NCE Program Evaluation Committee. Also see: Civil Engineering Research Foundation (CERF; 1996), *Creating the 21st Century through Innovation*, CERF Report #96-5016.E, pp 2-6.

ability) to carry over the innovation to the next project. There are exceptions, of course, as when critical path management moved from a project level to an industry-wide level.

From a chain-linked innovation model perspective, neither push nor pull properly describes the situation, although some clear examples of both may be found. It is important to note that an innovation in one portion of the industry often affects many others—for instance, innovations in concrete technology may cause changes in the use of wood and steel.

### Regulations and regulatory agencies

The importance of regulations is less agreed-upon than the importance of market pull and technology push, although some believe regulations have been the most important shapers recently.

Canadian regulatory agencies have several roles, none of which are strongly tied to market forces:

- ensuring that buildings meet minimum safety standards (the most common reason);
- setting standards for public good impacts such as those related to indoor air quality, the environment, energy efficiency, etc. (much less common); and
- setting standards related to building performance: utility, quality, long-term durability and costs, protection of assets, etc. (least common).

All of these may imply the use of new technologies. Clearly, when new codes are put into place that force the industry to use new methods or technologies, the regulatory process can be said to foster innovation.

In economic theory, standards have two additional types of economic effects which may promote innovations[9]:

- cost savings allowed by economies of scale in production: standards allow components to be compatible and interchangeable, in turn allowing mass production;
- cost savings from lower transaction costs in exchanges and trade: standards reduce the seller's cost of describing product specifications, and reduce the buyer's cost of verifying those specifications, in turn making product acceptance more likely (which increases sales).

However, there is strong agreement that although the process is intended to set *minimum standards*, in practice few builders construct buildings to more than the minimum required—customers perceive the code as adequate and don't think about the implications for long-term effects or building performance. Regulators are seen as equally unconcerned about long-term performance or costs.

There are strong differences between different types of standards. Most are derived in a top-down manner, and may suffer from resistance on the part of the construction industry. On the

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[9] Ross, Thomas W. (1991) *The Economics of Standards*, draft paper prepared for the CMID Standards Working Group. See also The ARA Consulting Group (April, 1997), *Draft Report The Economic Benefits and Role of Measurement*, prepared for the National Research Council.

other hand, if industry is actively involved in a bottom-up way in standards development, adoption may be swifter. In addition, prescriptive standards (that specify how a structure is built), are thought by most people to be less permitting of innovation than performance-based standards (that specify how a building should perform). Although it is theoretically possible to satisfy prescriptive-based building standards by proving that a given innovation conforms to the *intent* of the standard, the intent of most standards have not been specified in an objective manner. Some codes also contain product definitions that were never intended to be prescriptive, but end up disqualifying new products from being approved if they use entirely new technology which doesn't happen to fit the definition.

Thus to the extent that the intent of codes can be clarified, this may lower innovation barriers, and there is a trend in Canada to move to performance-based codes based on objective measures of performance and supported by formal national training for regulators and inspectors. Canada has a unique advantage in this regard since its principal construction R&D centre (the IRC) contains the national codes centre (the Canadian Codes Centre) and an innovation testing facility (the Canadian Construction Materials Centre).

There is some trend recently for Canadian governments (at all levels) to have become less "inteverntionist", and some previous public policies (e.g., with respect to energy efficiency) have disappeared or become much diluted. In turn this has slowed code development in areas related to public good.

There are also cultural differences. For example, the Japanese market is far more concerned about fire safety than is the North American one, and fire safety standards are mainly directed towards preventing fires in the first place, whereas North American standards are mainly directed at preventing fire spread. In another vein, although Canadian regulatory agencies set few standards related to social issues (e.g., noise transmission in multi-family dwellings), other jurisdictions such as the EC readily regulate in some social matters.

A general trend across all industries is for harmonisation of codes and standards. This is also occurring in the construction industry as world markets become more important and accessible.

Note that regulations don't address cost or revenue concerns, as do market pull and technology push.

### Summary

Two main factors appear to drive innovation: market pull, and technology push through the actions of regulatory agencies and suppliers. Market pull is a strong motivator for innovation. This pull is mainly to reduce costs, especially for commodity items (as many commercial buildings are viewed). For SME builders, market pull is the deciding factor in adopting any innovation — "will it help sell the building?". Technology push, although important, appears to be less important than market push.

Regulatory actions are a double-edged sword: although they ensure that buildings meet standards affected by the latest thinking and research regarding safety, and they also help to reduce industry's transaction costs, they have been less effective at promoting new technology related to public good impacts and (especially) building performance. (This is partially due to less-interventionist government policies in the recent past.) Once in place, prescriptive codes and standards probably inhibit innovation. Performance-based codes, on the other hand, may lower innovation barriers. Another type of push is through suppliers, who may strongly promote new products. Push may also be important when a new market opportunity arises. Most thinking on technology push suggests that it works best when industry and/or the end-users are actively involved in the technology development process. This is likely to be true for code development as well.

Finally, in this project-based industry, project-based innovation and innovation from individual inventors and stakeholders are important to respond to technical and financial challenges posed by individual projects.

### 3.3.2 What market situations tend to foster or hinder adoption of innovation?

#### *Risk*

Financial risk is probably the single biggest hindrance to innovation. The fewer the number of stakeholders who lose money (and possibly reputation) if an innovation fails, the more money each party is likely to lose, and the less likely the innovation is to be attempted. This applies equally well to designers, suppliers, constructors, and owners. However, innovation at the construction stage falls mainly to designers and constructors—owners and end-users don't share in this risk under most procurement schemes, and methods that spread the risk to end-users (e.g., through innovative, but possibly higher cost, procurement systems such as "cost plus") may reduce reluctance to innovate. Obviously the smaller the stakeholder, the less risk can be assumed. This is especially true given the low profit margins in construction, since risks are then proportionally more significant. When governments assume part of the risk, much larger innovations may be attempted.

Risk as a hindrance to innovation applies less to leasers and tenants as they usually have little control over the construction process. Risk can also apply to innovations in areas other than construction itself. For instance, development of building performance measurement systems (e.g., for air quality) that can be used by tenants may not be welcomed by owners and operators, who may put barriers in the way.

Legal liability can also be an issue. For example, in Australia performance-based, privatised (third party), building regulatory systems were introduced, but designers were then unable to obtain liability insurance. Legislation had to be introduced to allow indemnity coverage. Similarly the US Civil Engineering Research Foundation (CERF) operates the Highway Innovative Technology Evaluation Center (HITEC), which carries out work similar to that of CCMC (testing of innovative technologies) for the transportation industry. In order to operate within CERF, HITEC had to institute a number of procedures intended to limit the liability of both organisations if sued—essentially clients must sign waivers absolving CERF and HITEC from any liability, and professional liability insurance was obtained (with great difficulty).[10]

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10 Peter Kissinger, CERF/HITEC, personal communication.

### *Types of customers*

This factor strongly affects the need for, and interest in, innovation. Customers with the most interest in innovation are considered to be large owners such as municipalities, and owners of custom or highly-technical facilities. Owners of custom industrial facilities (e.g., refineries or nuclear power plants) are often forced to be innovative to solve technical problems, and are usually responsible for (and thus interested in) long-term maintenance. Many resulting process innovations are held confidential. Small users are often unsophisticated and less able to understand technical trade-offs.

Municipalities and many other public sector organizations are keenly aware of long-term performance issues, but their ability to respond through innovation is often severely hampered by two factors. First, they are often tied into a "low bid" procurement process, and, second, where political decisions are required there is usually a lack of hard, objective, data on which a decision can be based.

### *Procurement and ownership systems*

Procurement systems also have a strong impact on innovation. The sophistication of the client may affect the bid system used. Although "low bid" procurement systems should lead to innovations designed to reduce costs while maintaining performance, in practice they often lead to designs that employ very little innovation. Thus risk is reduced to all parties (contractors suffer if innovative building techniques cause them to lose money, and owners suffer if innovation leads to long-term durability and maintenance problems), but making performance improvements becomes difficult. Similarly, where cost savings innovations are employed, performance innovations are usually impossible.

Procurement systems that encourage bidders to use innovations are:

- "low price" but from a carefully-selected group of bidders;
- "bid, build, lease";
- "build, own, operate, transfer" (BOOT);
- incentive contracting (in which contractors and owners share in some way in cost-saving innovations);
- "cost plus" systems;
- "tight/loose" systems (performance is spelled out tightly in tender documents, but methods are left loose);
- "two envelope" system": the technical bid is evaluated on the basis of "best performance" without knowledge of bid price; the winner of the technical portion wins the job so long as price can be agreed upon.
- "Golden carrot" system: customers for new innovations pool together their resources to solicit bids for one large research contract instead of many small ones; this can lead to breakthrough improvements instead of many small incremental ones.

Alternate bid systems are increasingly used for large engineering projects but rarely on smaller ones. From an economic perspective, such systems spread both benefits and risks to more parties, contractors and owners alike. In general, those people who have accountability for building performance are those most interested in innovations that increase performance—procurement and ownership systems that foster accountability also foster this interest (although as mentioned elsewhere, the *ability* to innovate may not follow). In jurisdictions where longer-term warranties are common (e.g., 10-year warranties are found in the EC), expected operating expenses are an important part of the procurement process.

In any case, procurement based on performance may be limited by the ability to define and measure performance.

### Labour

The high cost of skilled labour is often cited as a driver for innovations that attempt to reduce labour costs, or reduce on-site time. There is a general trend to make more sub-assemblies off-site, especially as more sophisticated mechanical and electrical components are incorporated into the final product.

Another factor is the gradual loss of skilled sub-trades as traditional craftsmen disappear—entry costs are low in construction and many workers have few skills and may have little knowledge of English or French. This has driven research into "dumbing down" the products so that unskilled labour can use them, reducing emphasis on printed instructions for some products, and making pre-assembled products that go together quickly and easily on site. (This is an interesting contrast to most other industries, which usually emphasise additional training. There are some analogues in other sectors; e.g., in the automotive industry many assemblies and sub-assemblies are now modular and can't be repaired by even skilled mechanics. However, there is usually extensive training in new diagnostic and replacement methods.) Quality control remains a problem, however, as some new products and methods may actually be more complex than traditional ones and may require a different skill mix on the part of construction crews. For example, modular units may require some conceptual thinking instead of manual skills; new construction methods may also require more skills in business, marketing, organisation, and efficiency; and the move to off-site fabrication may require more factory-based training.

At the firm level, there are few large contractors left in Canada that employ a large fixed work force (this is also true in the UK). This also tends to reduce skill levels. An exception seems to be in keeping the service personnel used for long-term building maintenance, and this may be a trend in the industrialised building sub-sector (in which buildings are mainly assembled from pre-fabricated components made off-site, but for which customers expect longer warranties and service).

Finally, new technology that changes work force numbers, safety risk, or skills may require negotiations with the affected unions—in Canada unions involved in heavy construction in BC have apparently been flexible in response to such changes, although the increasing competition from open shops (non-unionised) has also had an impact here. However, such flexibility is reportedly not the case in other regions, and innovations using a variety of skills may conflict with union job descriptions.

### The economy

The economy has a strong impact on the perceived need for innovation. Where the market is strong, at first glance one might think this allows designers and constructors margins sufficient to encourage innovation, and clients with the desire for them. In fact, strong markets—especially where real estate speculation encourages quick "flipping", where building assets appreciate over time, or where the return on investment from retail or commercial space is very high—tend to encourage innovation devoted to speedy construction where buildings are commodities acting as "money machines", but discourage innovation devoted to other aspects such as building quality, performance, or durability. Tight markets, on the other hand, tend to encourage cost-cutting innovations. Approval of new, speedy assembly methods may also be encouraged in situations where very quick construction is required: good examples include post-war rebuilding in Europe (which stimulated large government investments in industrialised housing), and post-earthquake rebuilding in Loma Prieta, California (which encouraged innovative procurement processes, that in turn allowed innovative repair technologies).

### Types of markets

It is easier in general to promote innovations in new markets than existing ones, and stakeholders often innovate strongly in order to enter new markets—e.g., entering the global market, meeting new cultural expectations, etc. However, export markets have to date been little exploited by Canadian firms with respect to innovative technology. Various trade, cultural, language, and regulatory barriers are cited. In addition, some markets and technologies (e.g., heavy equipment) may require substantial long-term on-site service and maintenance that are difficult for Canadian firms to provide.

Manufacturers who have had proprietary patents expire are strongly motivated to find new patents to replace them. This search is done from both the technology push and market pull viewpoints, but people are "always on the lookout for really new things."

There are some other factors. As the building stock ages, there appears to be more thought given to repair technologies. As the population ages, more thought is being given to appropriate design for a greying population (e.g., smaller homes, easier access).

### Other factors

Changing demographics tend to foster innovation. Examples include differing housing design expectations of different immigrant groups, and the impact of a "greying" population.

### Summary

The main factor hindering innovation is risk. The financial and legal risk to designers and constructors effectively stifles innovation in any procurement situation that does not allow room for either error or compensation for the extra time and effort needed to implement new technology. Since owners, operators, and end-users usually don't share in this risk, the potential costs of innovation are shared among too few stakeholders to be acceptable. In addition, the smaller the stakeholder, the greater the proportional risk. A corollary to this factor is that procurement policies strongly affect innovation: "low bid" systems and those that are too stringent in their prescriptions kill innovation, whereas any system that accepts flexible design and (especially) that allows shared risks and benefits among the various stakeholders will foster innovation. Large owners tend to be interested in innovation because of its potential to reduce life-cycle costs, but only if politics and financial issues allow it (e.g., "low bid" procurement methods, and the separation of capital and operating budgets for large owners such as government tends to eliminate their ability to support life-cycle cost saving innovations). Finally, when real estate markets are strong, there is little incentive for developers or owners to innovate—the property will sell anyway, and they're not likely to own it for long. Other factors hindering adoption of innovation include the lack of objective performance data on innovative technologies, and the lack of skilled labour and fixed work forces.

### 3.3.3 What types of innovation are most readily adopted, and why?

#### *Nature of innovation*

On the commodity side, innovations are driven by cost. On the decorative side (e.g., for high-end clients such as retail malls and corporate headquarters interested in architectural details) innovation is usually driven by creativity and ambience, with cost considerations secondary—in some sub-sectors (e.g., gypsum wall and roof panel systems) most innovation is being driven for decorative reasons and latitude is much greater than for innovation done for cost reasons.

SME builders usually feel most comfortable with small, incremental innovations. Large fundamental innovations only succeed when large stakeholders are behind them, or government mandates them and assumes a portion of the risk. On the product side, constructors become increasingly concerned about longevity and durability issues the longer they provide after-sales service and maintenance, and become correspondingly unwilling to risk trying new technology whose durability is unproved. There are many examples of innovations that didn't work out (e.g., vinyl windows satisfied code requirements for thermal breaks, but manufacturing techniques left lots of holes that leaked), or were poorly integrated into the building as a whole (e.g., tightly-sealed buildings were energy efficient but had serious problems of rot and mold caused by moisture build-up).

Residential contractors report that potential home purchasers are most interested in "things they can see and touch." They aren't very interested in "what's inside" except to know things are built to code. As one respondent put it, homeowners "are buying fins at the moment."

Some respondents believe that process innovations provide the most potential for large benefits, especially if obtained through gradual, incremental improvements arising through close relationships among different stakeholders. Innovations are believed to be most readily adopted where their impact on the building system overall is understood.

#### *Product, process, system, and design innovations*

All types of innovation are important. A cursory review of recent innovations in commercial structures[11] indicated that roughly:

- 50% included significant product innovations (e.g., use of metal and floor roof decks);
- 50% included significant process innovations (e.g., computer-aided design)'

[11] Bernstein and Lemer (1996) *Op cit.*, page 42.

- 25% included significant system innovations (e.g., critical path method of scheduling); and
- 10% included fundamental design innovations (e.g., curtain wall construction).

The total sums to more than 100% because many innovations overlap categories (e.g., the use of tensile roofing fabrics involves new construction processes and new designs). There is probably more overlap than indicated above—we have merely tried to indicate the main categories represented in each innovation.

### *Performance issues that have enjoyed little innovation*

There are many building performance issues that appear to be significant but that have not been addressed to any great degree. These include:

- energy efficiency, including that of appliances and furnaces as well as that of the building as a whole (although the federal government through IRC, CMHC, and Natural Resources Canada have done a lot of work in this area, many industry observers believe that much more can be done both technically and in terms of developing market interest).
- long-term (and even near-term) durability of structural elements, envelopes, roofing, etc.
- need for, ease, and cost of maintenance
- ventilation
- indoor air quality, and associated health issues (again, a considerable amount of work has been done by federal organizations regarding ventilation and, to a lesser degree, outgassing source control, but up-take in the market has not been as high as hoped for, and there are several other IAQ issues as well)
- indoor environmental controls, especially for tenants
- integration of heating, cooling, and ventilation systems
- poor quality assurance

To some extent performance issues have been resistant to innovation because there are few agreed-upon standards for measurement. In addition, the recipients of benefits from improved performance have been mainly limited to end-users so far, with poor capture by the innovators themselves (unless they are also the owners/end-users).

### *Summary*

On the commodity side, cost-savings innovations are best-accepted. On the decorative side, innovations are driven by flexibility and creativity. Innovations that increase performance have not been particularly of interest to the industry or end-users (perhaps partially because of a lack of agreed-upon measurement standards), although for some issues such as energy efficiency and ventilation government has done considerable research. SME builders are most comfortable with small, incremental innovations, and large innovations are only accepted when large stakeholders are behind them or they are mandated through code. Residential customers are more interested in design and features than performance or longevity. There is a trend for constructors to offer longer warranties; this is increasing their interest in performance innovations and life cycle costs.

Overall, process and product innovations appear to be roughly equal in importance. Systems innovation has the potential for large cost savings, but only in certain restricted situations. There are relatively few really fundamental design innovations compared to other types.

Finally, it is difficult for the innovator to capture the benefits in many areas of this industry; e.g., there is less opportunity for protecting intellectual property than usual; and end-users, not designers, owners, or constructors, benefit from performance innovations.

## 3.4 Who innovates, and why?

### 3.4.1 Who innovates, and why?

#### *Overview*

There is no general agreement as to which particular stakeholders are at present especially innovative. Although many government owners are often cited as being the most resistant to innovation (mainly due to "low bid" procurement practices, and the separation of capital and operating budgets), in some special cases it may be quite innovative (e.g., DND is interested in objective-based building guidelines). It was agreed that the size and sophistication of any individual or firm is quite important, with specialised industrial facility owners being quite willing to innovate. Finally, there is general agreement that it is the owners who will ultimately drive innovation, but only if they themselves benefit.

In general, there is a trade-off between cost, time to completion, quality/performance, and risk, that each stakeholder must take into account when attempting innovation. For suppliers, access to markets is also considered. Typical reasons for innovation include:

- to manage or reduce the cost of new installations, including overall costs and costs of sub-assemblies (e.g., reduce costs of labour or materials);
- to reduce costs of materials handling and inventory;
- to use products and processes suitable for a less-skilled work force;
- to shorten time on-site or to complete the project;
- to improve health and safety during and after construction;
- to increase convenience of building use;
- to increase market appeal to buyers;
- to improve professional reputation.

#### *Innovation trends by stakeholder group*

Possible innovators include:

- Owners and operators in the public sector: Owners may innovate, and may force contractors to innovate, in order to get the best technology, the best performance, and the best long-term durability and low maintenance costs[12]. However, this depends on the

[12] There are some special cases here, such as interest within the public school system in indoor air quality issues. Also, the federal government does not have to build to code. As a result, some large owners such as DND are quite innovative owners (IRC is in fact preparing objective-based building "guidelines" for DND).

budgets for construction and operation being in some way tied together—this incentive will be lost if the budgets are separate. (Owners forcing suppliers to innovate is an unusual method of technology transfer, although there are a few instances in other industries—for example, innovations in medical instrumentation and techniques have been driven partially by public interest.) Large sophisticated owners of facilities that represent large assets are most likely to innovate as they are most aware of the costs of not doing so. Where owners are not responsible for performance, however, low bid systems may predominate.

- Owners and operators in the private sector: Governments have had two contrasting roles in technology development. First, as important *owners* of construction products, and as watchdogs of public safety, they have traditionally been very involved with technology research, at least at the federal level. However, as *buyers* until recently governments have mainly focused on low initial cost, or been unable to pursue opportunities for longer-term cost savings.
- There may be a trend for reduced role of government as the major purchasers or owners of construction products as governments downsize. If so, the state will not mainly be providing R&D services to itself—this may necessitate a shift in research priorities.
- Developers focus strongly on the marketing side, often providing designers and builders exactly what will sell, based on what sold in the past.. They find that in office spaces there is not a lot of interest in interior durability since tenants change frequently and usually remodel when they do. For retail spaces, remodelling is often done simply for a "fresh look". If developers intend quick sales turnover, they have no reason to care about innovations so long as their buyers don't.
- Designers, architects, and engineers: Designers, architects, and engineers typically innovate to promote their professional reputation, to reduce costs, and to win bids. There are differences between project-level innovations and system-wide ones, as well as structural innovations versus decorative ones (decorative innovation may depend on new technology). Overall this group is not considered to be especially innovative because of the constraints of tight procurement specifications, need to win "low bid" tenders, and potential liability problems if innovations fail. Should such restrictions be lessened, the multi-disciplinary nature of design may allow significant innovation to be fostered.

  In Canada, designers are independent of their customers, and usually don't share the same needs or have an effective way to resolve disputes. If closer linkages with customers develop, this relationship may change but the effects are unknown . (In some other countries, there tend to be large vertically-integrated construction companies with designers in-house working on behalf of owners.)
- Manufacturers and suppliers: Manufacturers and suppliers normally innovate to lower costs and are substantial innovators, although often driven by requests from designers.
- Builders and contractors: These are often resistant to innovation because innovating may require new skills, high risks or high costs. However, sub-trades are often interested in labour- or time-saving innovations.

- Custom builders and contractors: Some individuals are known to be early adopters of innovation; their influence is unknown.
- Pre-manufactured or "industrialised" builders and contractors: Pre-manufactured and "industrialised" builders can be very innovative in areas of speed and ease of assembly, as well as higher-end uses and design flexibility using standard modular pieces. (Industrialised systems for complete housing units have a poor track record in North America, having been neither cheaper or faster to build, and they are associated with low-end housing. However, in some countries such as Japan they have recently made inroads into the housing unit market, pushed by large manufacturing concerns. In addition, industrialisation has a better record for innovative decorative elements, and pre-fabricated housing components {e.g., trusses, windows} are also increasingly popular in North America.)[13]
- Renovators versus builders of new products: Renovators often must be very innovative as they are constrained more than builders of new construction, but much of the innovation is project-specific.
- Labour and workforce: No data was found.
- Professional associations : Professional associations have not been very innovative to date.
- The general public (e.g., for housing affordability, environment, energy consumption, indoor air quality, etc.): The general public is considered by most students of the industry to care little about innovation, as homes aren't seen as technological devices, and comfort and tradition are more highly-prized than performance.

### *Summary*

The most important innovators appear to be large owners who are responsible for long-term performance, maintenance, and repair. Such owners include governments. However, the nature of procurement policies, the difficulty of certifying performance to political interests, the recent strong real estate market, and the frequent separation of capital and operating budgets[14] often ties the hands of governments. Where some freedom exists, these owners may be significant receptors for new technology and often become involved in research in order to gain access to the latest thinking on performance issues—they then force suppliers, designers, and constructors to build to these new standards. Large private sector owners such as owners of industrial plants are also often significant innovators but tend to hold these innovations confidential. Suppliers may be innovative on the product side, although mainly on the side of cost savings.

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[13] Gann, David M. (1996), *Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan*, **Construction Research and Economics**, 14, pp 437-450.

[14] An excellent example is in the lower-than-expected take-up of IRC research results related to reducing the maintenance and repair costs associated with concrete parking garages. Although very simple maintenance procedures were found to be capable of savings substantial sums of money (e.g., a few millions of dollars per garage over its lifetime), one of the public sector organizations involved in the research has essentially ignored the results, partly due to the strong market, and partly due to a rather complex interaction of "who pays what".

Government also has a role as the provider of public good research—in this capacity it is a very significant innovator.

Other stakeholders such as designers, developers, building contractors, labour, and professional associations are less important as innovators.

### 3.4.2 How do government R&D and testing agencies affect the innovation system?

Government R&D and testing facilities investigate the basic physics of construction materials and methods and are crucial links in the process, filling the "market failure" gap. Government provides expertise to show that new products and processes meet technical requirements, and may be able to address market issues such as durability and maintenance. They can also assist formation of consortia among major industry and regulatory stakeholders that would not exist otherwise; e.g. for development of voluntary performance standards, to share risks, etc..

#### *Direct, Indirect, and System Benefits Resulting from Research Efforts of Government*

Recent work indicates that research benefits from government R&D agencies consist of three main types[15]:

- **Direct benefits to partners and others**: These arise when the research results of a specific project have been directly used by partners, non-partners, end-users, or society as a whole. For instance, the application is typically a new or improved product, process, or service. Benefits of this type are usually relatively easy to understand because there are increased sales revenues and/or cost savings associated with using the research results. This is especially true when the research leads to a new product that's sold in the open market. However, visibility tends to be lower for benefits related to public policy issues such as health and safety or the environment, because these benefits are widely distributed and it's much harder to estimate they are worth.

  Although direct benefits usually accrue just to partners of the research agencies, sometimes there may be a cluster of related firms (e.g., designers, producers, distributors, etc.) that all benefit from a particular project. In other cases, there are also "end user" benefits. (There are almost always end user benefits, but they can't always be easily seen— thus most analyses tend to focus on the benefits to manufacturers and producers.) For instance, a new type of wall construction may allow contractors and designers to increase their business sales, but may also allow home owners (the end users) to reduce their heating bills or live more comfortably. For regulatory-related projects, the end users may constitute the general Canadian public.

- **Indirect benefits to partners:** These are essentially everything **other** than direct benefits (although we have separated out system benefits; see below). Indirect benefits occur when access to, or involvement with, the government agency allows partners and

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[15] For a complete review of the literature and a discussion of the types of benefits of government R&D, and measurement implications, see The ARA Consulting Group Inc. (1997) *Measuring the Impacts of Public Investment in Research & Development*, Prepared for the National Research Council.

non-partners to obtain other "fuzzier" kinds of benefits. Partners can increase their overall innovative ability because they've increased their knowledge and research competence (e.g., they may apply new technology in areas not directly associated with the research projects), or they may be able to make better investment decisions because of their exposure to the research agency (e.g., they may avoid unpromising new technology). There may be other benefits such as reduced risk in starting up new ventures or in hiring people with new skills (because the partners are more competent to judge the worth of these), or from exposure to other companies with which they form strategic alliances. Although indirect benefits are harder to specify and harder to measure than direct benefits, they may be as important — or more important — to some partners[16].

- **System benefits** These indirect benefits[17] affect the industry as a whole, or sub-groups of it, not just research agency partners. There are at least two types of such benefits. First, research activities may affect the local **innovation system** related to a particular industry (e.g., through attracting firms to the area that would not otherwise be there, increasing linkages between firms, providing testing services, influencing college and university curricula, etc.), thus helping create a centre of expertise. Second, there may be **industry-wide system benefits** in which the research agency's work leads to the development of new markets in which many firms can share (e.g., when international agreements on standards allows companies to enter new markets abroad).

#### *Summary*

Government has a very significant role to provide research and testing services to the industry, and can potentially fill the "market failure" gap. However, the traditional role has been to focus on research into new materials, products, and (to a much lesser extent) processes. These all will eventually result in direct benefits to the industry. There appears to be room for more thought as to government's role in providing indirect benefits to private sector partners (e.g., consortia), as well as to its role in increasing the innovation system. Given the discussions in preceding sections, there also seems room for more research on non-technical barriers to innovation.

### 3.4.3 How much innovation results in open access by the industry and customers (e.g., that done by government) versus proprietary access (e.g., that done by or for individual firms)?

There are examples of proprietary (patented or copyright) product and process innovations in this industry, but overall it is probably harder to protect intellectual property (especially for process innovations) in construction than in many other industries. For example, some suppliers are reluctant to pursue export markets for fear of having products copied and imported back at a

[16] We found this when investigating why firms participated in research consortia created by NRC's Institute for Microstructural Sciences, for example. The partners didn't care much about direct benefits from new "NRC products" — they really only cared about being "plugged in" to the latest R&D.

[17] There is an unfortunate overlap of terminology here. "System benefits" is described in the paragraph above. "Systems research" refers to research that helps coordinate the many inputs and processes in assembling large, complex products.

lower price. However, at least some large firms follow a model similar to those in microelectronics—a jump on the competition of 2-3 years in the market is considered worthwhile even if a process cannot easily be protected.

An interesting point is that the design industry is composed mainly of individuals who are used to publishing in the open literature (like university researchers), and are loath to patent, copyright, or hold secret an innovation even if it might result in substantial revenues (again, also like university researchers, at least until recently).

### 3.4.4 Are there regional "innovation centres"?

Few regional centres exist, although the San Francisco Bay area is noted as somewhat important. One of our SME contractor respondents travelled there regularly to see the latest technology and designs in place. Boston and Calgary are also sometime cited, and the Construction Industry Institute at the University of Texas was mentioned.

### 3.4.5 What is the role of "champion" individuals in the innovation system?

Many people believe that "champions" and "early innovators" are important links in the innovation process. Some individuals are natural innovators who invent for the sheer enjoyment of it as much as for profit (and often in the face of losses). These individuals may be employed by large owners, contractors, or research organisations, and may not be restricted to the construction sector. Probably most innovation will be on a project basis. However, very little further information on this topic was found. (This is a possible area for further exploration.)

## 3.5 How does the industry as a whole learn about innovations?

Much more investigation needs to be done of how new knowledge disseminates in the industry. However, there is substantial agreement that information linkages and flows in the construction industry are weaker than in many other industries, although the exact nature of the information and feedback loops is not well known (and obviously vary greatly from project to project, and stakeholder to stakeholder). Much dissemination is probably by word-of-mouth, especially for "low tech" innovations. Although there are many technical journals and publications (including a lot of information from commercial sources), these may not always be read by the many players that comprise "construction, and the best ways to package and present information for different audiences is also unknown. Many of these publications are free, reducing the incentive for the providers to improve their quality or utility.

One respondent believed that product innovations tend to diffuse through market sales processes; process innovations, through work place collaboration; and systems innovations, through coalition ventures. There may be a tendency for process and systems innovations to have more sophisticated audiences.

Some limited use is being made of electronic communication; e.g., technical specifications may be available on-line in an interactive way from large suppliers. This and product training may help "add value" for commodity products.

The construction industry suffers from an unusual gap: owners, operators, and end-users are often not the same people—this gap probably substantially reduces feedback from ultimate end-users to designers and constructors about performance issues.

Training issues are not addressed in great detail in the literature we reviewed. One respondent pointed out that training could cause labour to expect higher wages, thus hindering the incentive to train.

There is not much in the way of "think tanks" in Canada for bringing together major stakeholders to drive a bottom-up approach to solving technical problems. The industry in most countries suffers from a similar lack of long-term strategic thinking, although there are some US and international examples (e.g., the recent Technology Foresight exercise in the UK was a precursor to such strategy-building, in that it was intended to raise the consciousness of industry to specific opportunities; other examples include the World Federation of Technical Assessment Organisations, the US National Council for Civil Engineering Research).

Finally, communication is fragmented by the fragmented nature of the industry itself.

## 3.6 A Conceptual Model of Innovation in Construction

As should be clear from the preceding discussion, a single model for this industry, much less a single model for innovation within it, could not reflect the necessary diversity. Every issue answer seems to have a "but" attached to it. However, we have tried to meld some existing models of the industry and of innovation in a very simple conceptual way.

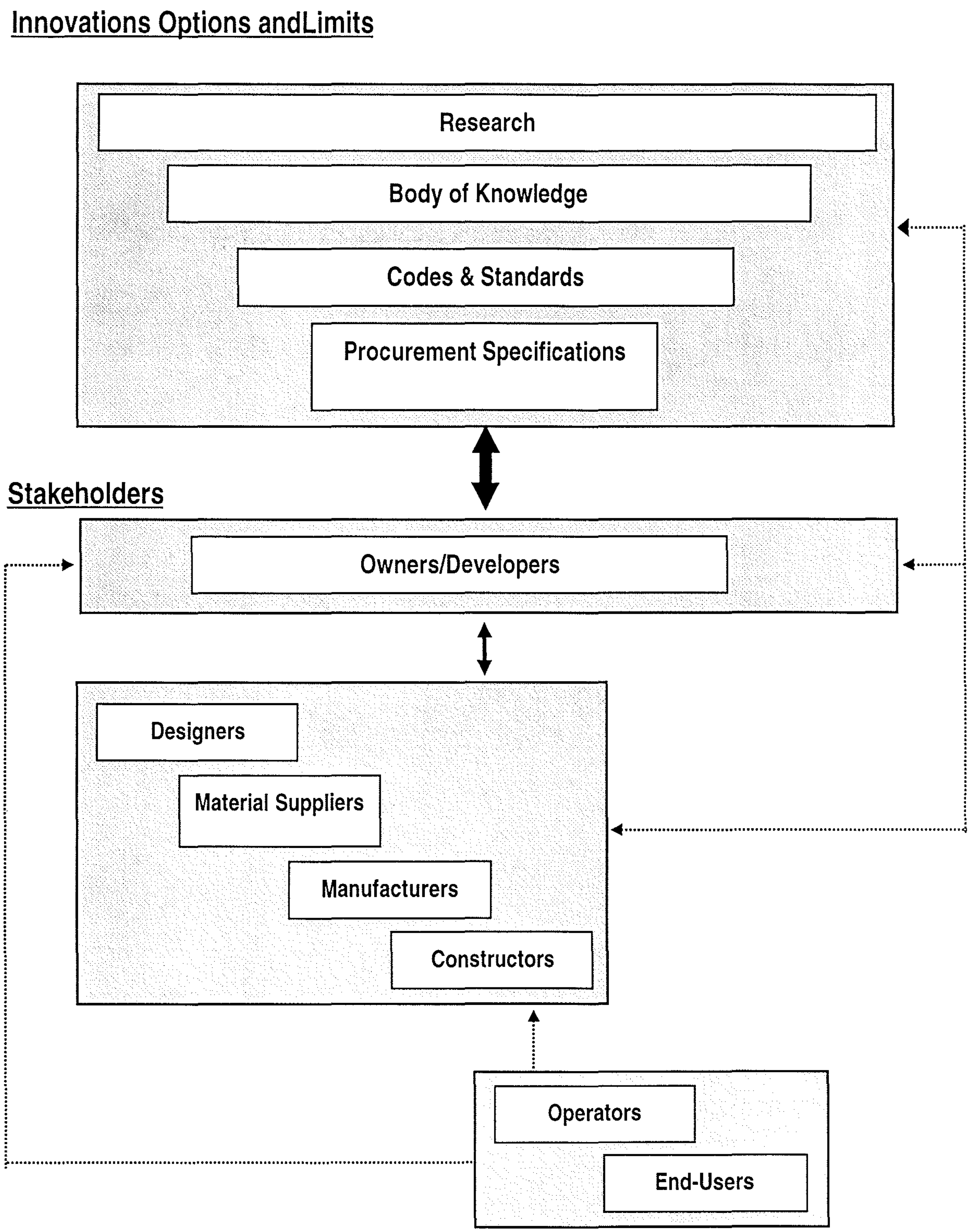
Exhibit 3.1 melds the "stakeholders" model of Bernstein and Lemer with the innovation model of Kline. The solid arrows show the more important ways in which information flows within the system, with dotted lines indicating weaker flows. Some points of interest:

- In Kline, people faced with a technical challenge of some sort would first investigate the technical and research literature to see if a solution existed, and only then would instigate a research project. In our model we have put two additional layers between stakeholders who are potential innovators and these two sources of knowledge: (1) Procurement specifications: since most buildings are built to some sort of procurement specifications, this would be the first source of detailed technical knowledge that a potential innovator would consult. This source, however, can act as a barrier—the specifications can be so detailed that no room for innovation is left; (2) If the procurement specifications allow innovation, the codes and standards would next be consulted (the time order may be reversed, but that probably doesn't matter). Again, innovation will only occur if the codes appear to leave open this option, after which either the innovation is adopted (subject to the usual procedure of testing and approval where required), or options from the body of knowledge and/or active research can be explored. Research organizations such as IRC may not first consider these two additional barriers, but all other stakeholders would.
- Not shown are that any and all of the stakeholders can explore the upper box of innovation options and limits (e.g., designers, constructors, etc.). In addition, each stakeholder will go through the chain of innovation stages shown in Exhibit 2.1 (e.g., manufacturers would consider market findings, analytic design, detailed design and

testing, production, and distribution and marketing, and could address options and limits for innovation at any stage).

- Also not shown is that there are information feedback loops within each major box; i.e., designers, material suppliers, manufacturers, and constructors all interact with each other and pass along information about innovation as found in Kline's model.
- Note that at this point we believe the information flows to and from operators and end-users tend to be weak. However, considerably more needs to be known about information flow among stakeholders.

**Exhibit 3.1: Innovation Model: Information Flow**




Adapted from Bernstein & Lemer (1996), and Kline (1985)

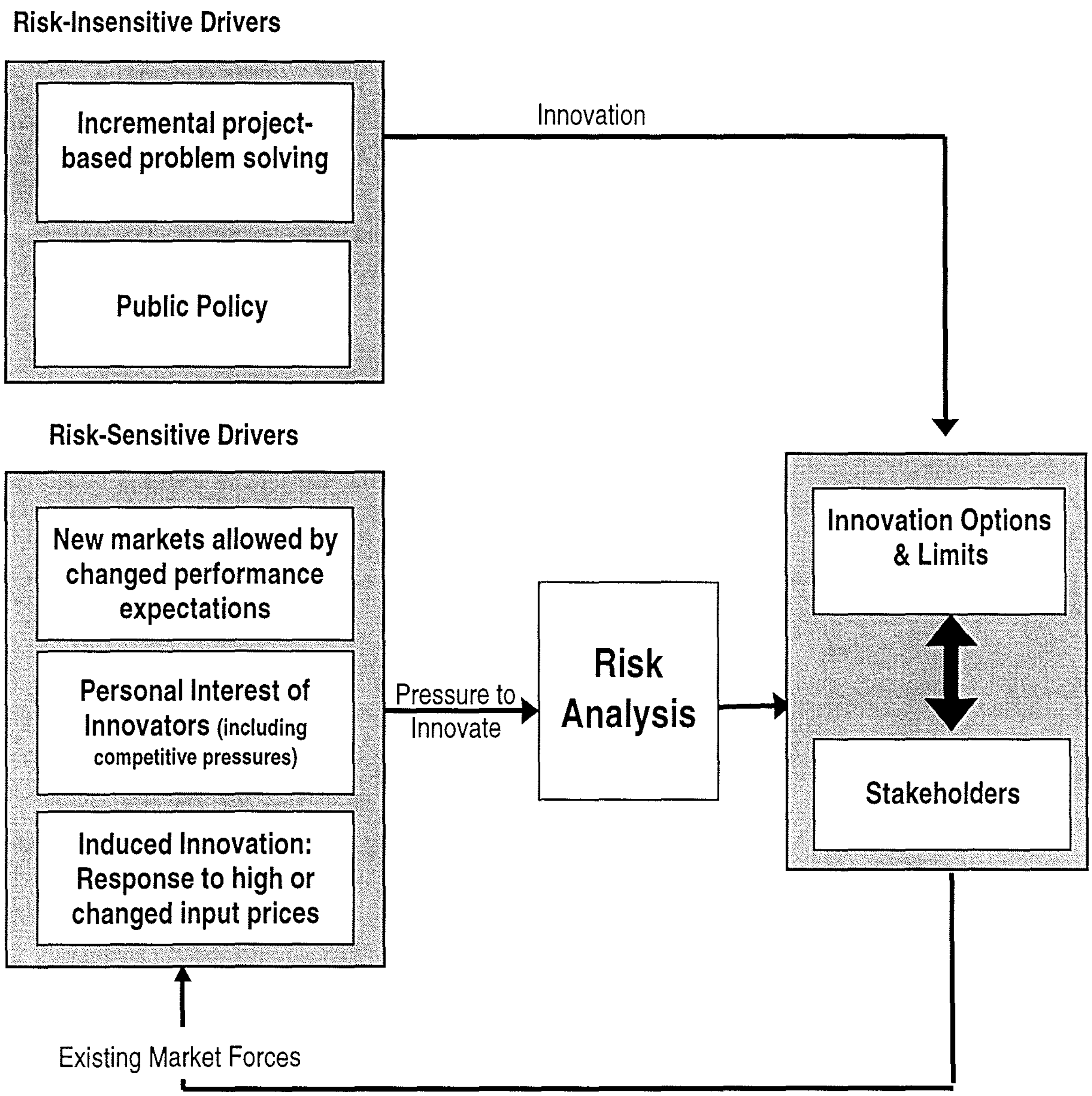
Exhibit 3.2 adds the "why" of the innovation model. There appear to be five main reasons why innovation occurs:

- project-level innovation driven by individual technical problems and solved by individual stakeholders, such as those caused by site variations; these tend to be incremental in nature and may or may not transfer across sites and innovators;
- because of public policy, as through development of codes and standards, but also through research into best practices, new materials, and so forth that may not go into code. These innovations are usually derived from publicly-funded R&D organisations.
- the individual interests of private sector innovators (including their personal interest in innovation, desire to save costs, need to keep costs low to win bids, desire to capture more of existing markets, desire to enhance reputation, etc.);
- the new markets allowed by changes in performance expectations, such as when the need for improved flexibility in siting equipment on industrial shop floors drives innovations in power delivery systems.
- induced innovation which drives part of the private sector free market in response to existing high prices or changes to input prices;

Note that the first two types of innovation are relatively little affected by considerations of financial risk and liability, while the last three types are strongly affected by perceived risk. All factors produce pressure to innovate. This pressure is then filtered through the innovation process as shown in Exhibit 3.1, which includes the need to address innovation options and limits, to consider possible path dependencies forced by the need to fit into existing technologies and methods, and so on.

Appendix B compares innovation in the construction industry to innovation in other sectors. Note that the construction sector has a number of unique features.

**Exhibit 3.2: Innovation Model: Driving Forces**



## 3.7 If Airplanes Didn't Have to Fly— Some Implications of the Innovation Model

### 3.7.1 Implications for thinking about innovation in construction

This section is intended as a discussion piece only. We have not had the opportunity to fully consider the implications of the construction innovation model. Some thoughts are:

1. The industry really is project-based. Despite that fact, much of the literature on increasing take-up of technical innovation seems (at least to us) to implicitly wish construction were more like manufacturing, and it's easy to find discussions of how much better the industry would be if only it were more "industrialised", standardised, modular, and so on. This seems to us to be a mistake—it's like saying, "If only airplanes didn't have to fly, think how much cheaper they could be!" Unfortunately, airplanes stuck on the ground aren't airplanes, they're trailers. Wishing the industry could be made less project-based risks ignoring the essential—even defining—project-based nature of construction.

   On the heavy construction side there will always be site- or usage-specific considerations that force custom approaches to many aspects of facility construction. For residential and some commercial office buildings, humans (in North America at any rate) have shown willingness to expend enormous amounts of time, energy, and money to create variable (as opposed to standard) living and working spaces, and often find standardised building abhorrent (or else everyone would live in trailers). This need is virtually never discussed in the construction innovation literature we reviewed. Nor is the fact that a large amount of building innovation effort goes into the decorative, even artistic, aspects of construction, which are also features of project-based work.

   We believe this curious paradox in viewpoint may stem from the unusual gap between owners and developers on the one hand, and operators and end-users on the other. This allow the needs of operators and end-users to be rather easily ignored[18], especially in areas of residential and office buildings, and perhaps to a lesser extent in "standard" industrial building.

2. Given the above, stop trying to make the leopard change its spots. Without denying that more "manufacturing-like" innovation has its place, more effort should be explicitly directed towards finding ways to encourage innovation in a project-based, highly individualised and customised industry. This might, for example, involve studying other similar technical, project-based industries for alternate innovation models. We're not sure how many there are, or whether innovation is any better-understood in these other areas, but consider a review of industries such as shipbuilding, environmental damage control and mitigation (at the plant or project level), health care, or the consulting

[18] And perhaps with significant consequences. There are several striking examples of "industrialised" housing projects which have been disasters from the point of view of the occupants. It does not seem unreasonable to suppose that the design and construction methods have some responsibility.

industry. Possibly, other project-based, individualised, but non-technical work may also provide ideas (e.g., art, labour negotiations, tourism development).

3. There needs to be much more thought given to *why* innovation is initiated, and *why* end-users may want innovation. This should include not only technical, economic, and public policy considerations, but also personal and interpersonal considerations—it's individuals, not economics, who innovate, and individuals who use the innovations.

   Further to this point, do not focus solely on the technical and performance aspects of end-user needs when considering residential and commercial construction. Many emotional and interpersonal factors are extremely important in this field, and should not be ignored any more than they are in automobile design or the fashion industry.

4. The high risk of adopting technical innovation distinguishes construction from most other sectors. The risk factor is well-known, but efforts to solve the problem appear less common than those to solve (easier) technical challenges.

5. Although innovation occurs only if someone can capture the benefits, don't restrict thinking about this to how the industry as a whole can capture benefits. In a project-based industry one only needs to assure that *someone* can capture them—this may mean only one stakeholder firm, or even one person.

6. Avoid thinking about innovation as being restricted to "formal research" such as that carried out by university or government researchers. Although perhaps there has been less transfer of this formal research to the industry than in other fields[19], there has clearly been a great deal of innovation by stakeholders. Much of this has been incremental project-based innovation, and much has been process or systems innovation, both of which are less amenable to measurement through traditional economic indicators such as patents, sales revenues, etc. More investigation of innovation at levels of the project, individual companies, the sub-trades, on-site creativity, and so forth would seem warranted.

7. In such a fragmented industry, cooperation and collaboration among stakeholders are critical elements of a successful make-over. These elements are also required to understand the needs and risks of stakeholders and to address common problems affecting many stakeholders (e.g., leakage). There are good reasons for believing that communication in general, and especially communication about innovation, is weaker in this industry than in most others: collaborative efforts are one way of overcoming this lack.

   There are many useful models available for collaboration. In the recent past, program-based research and technical collaborations have become increasingly accepted, and participants almost always find things work out far better than they hoped and problems were far less serious than they feared. Such collaborations have been across firms (e.g., consortia formed by NRC's Institute for Microstructural Sciences); across technical and research disciplines (e.g., the Eco-Research Program); across industrial sectors (e.g., the

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[19] This is certainly debatable, as all sectors have experienced great difficulty with such technology transfer.

SPARK program of the Science Council of BC); across university, government, and industry sectors (e.g., the Networks of Centres of Excellence program); and across governments and continents (e.g., the U.N. Intergovernmental Panel on Climate Change). These examples also encompass research from the very basic (e.g., the International Human Frontier Science Program), to the very applied (e.g., the Energy Research and Development Program).

### 3.7.2 Implications for public sector R&D organisations

The ultimate goal for public sector R&D organisations working in the construction field should not be to simply investigate and refine new technology. The goal should be to cause effective technology transfer, thus creating private sector benefits or increasing the public good. Therefore an organisation that only carries out research on new and better building materials, products, and designs is missing the point. The present review clearly demonstrates that take-up of innovation isn't primarily affected by the availability of, or knowledge about, new technologies. Lack of technology simply isn't the main problem.

Instead, the most important factors affecting take-up of innovation are the project-based nature of the industry, the financial and legal risks to innovators, certain procurement practices, the difficulty for innovators to capture benefits, and prescriptive codes and standards. A public sector R&D organization has two main options for technology transfer: (1) forcing it by embodying innovation in the regulatory process; and (2) encouraging it through non-regulatory means. Both options ideally require significant user input in order to be effective, and both ideally require the public body to take non-technical factors into account[20]. All suggestions below are based on this fact.

1. Overall, the focus of the organisation must be on effective technology transfer, not on science *per se*. Every research project must be initiated with technology transfer in mind—Who will use these results? How will they learn about them? Why will they use them? Why not? What benefits will result?[21]

2. Since the industry is fragmented and diverse, with relatively poor information feedback loops among some stakeholders, public research organisations can help identify the market signals that are obscured by this fragmentation, and can help provide a coordinating and strategic planning role. Such a strategic role would be best served with the very active participation of stakeholders in industry, regulatory agencies at all government levels, and end-users, as noted in section 3.3.1 under "technology push".

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[20] Although the specific factors differ from other industries, construction is hardly unique in this regard. Technology transfer in all fields is strongly affected by non-scientific factors such as lack of industrial receptor capability, lack of venture capital, regulatory hurdles, international competition, and so on. Research organisations and programs in other fields are also slowly learning that it isn't lack of good science that's the main problem, it's ways of getting the science to the users—to be effective, considerable effort has to be expended in these non-scientific areas or the science goes to waste.

[21] We note in passing that **Canadian** benefits should be focused on first. Although providing benefits to humanity in general is part and parcel of scientific thinking, in a Canadian technology transfer organisation one must first think of Canadians. Investigation of a problem that doesn't occur in Canada should have minor priority.

This will ensure that the government agency pays suitable attention to stakeholders needs (e.g., the industry need for cost- or time-saving innovations).

3. The driving force behind strategic planning would be fourfold: (1) Identifying market and stakeholder needs (including export needs where feasible) that cannot be satisfied by the industry alone; (2) Identifying public policy and/or social needs; (3) Identifying research and technology needs for government owners and operators; and (4) Addressing the risks, barriers, and constraints to innovation, and to the take-up of innovative research results (which are not the same thing). Identifying the "why" that drives the need for innovation is the first, and most important, part of the strategic planning process—one must be able to answer "Who is the client for this innovation?" Some such strategic planning has already been done in other countries[22]. In other words, don't focus on technology push.
4. The planning process for research projects should explicitly address — and propose ways to overcome — the various barriers to technology transfer. Where appropriate, the agency may take a lead role in attempting to lower these barriers (e.g., through investigation of alternate regulatory or procurement practices).
5. Cooperation, collaboration, and communications among various stakeholders should be strongly encouraged. In particular, closing the gap between end-users, owners, operators, leasers, and developers would be very useful. It's important not to simply follow the "scientific model" of communicating about innovation through journal publications. Most other stakeholders won't read the journals, nor is simple knowledge of the innovation the main barrier to its use.
6. The impacts of existing and alternate regulatory and building inspection systems should be actively investigated; including investigating ways of specifying objective performance-based codes and standards. International harmonisation of standards should also be investigated: this is a theme world-wide and means Canada has to stay abreast or fall out.
7. Research should not focus only on product and materials innovations, but also on process and systems research.
8. Providing indirect benefits, innovation systems benefits, and industry-wide system benefits may provide a significant opportunity for government in this role. Currently the private sector is receiving little in the way of indirect benefits from government R&D in the construction field; there is relatively little thought (or coordination) given to improving the innovation system; and the dissemination of industry-wide system benefits, while good through the codes and standards process and the CCMC, is not well understood in non-code areas.
9. Ways of improving the capture of benefits to innovators should be explored. This would include ways of sharing costs, risks, and benefits to more stakeholders than is now the

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[22] E.g., CERF (1996), *op cit.*; and Loveridge, Denis; Georghiou, Luke; and Maria, Nedeva, (September, 1995) *United Kingdom Technology Foresight Programme*, a report to the Office of Science and Technology, Programme for Policy Research in Engineering, Science and Technology (PREST), University of Manchester.

case. There should be inclusion of non-technical issues such as procurement practices and liability issues in the planning process.

10. Ways of educating all stakeholders as to the true costs and benefits of existing and new technology (including life cycle costs and benefits, where relevant) should be investigated, and placed in a performance-based framework.
11. More consideration should be given to training issues. For instance, investigate opportunities for industry-wide training needed to use, operate, and maintain new technology. This would include needs implied by changing skill mixes that may be required (e.g., business, communications, coordination, processes, conceptual thinking). In-house training and education for large owners and operators is another possibility.
12. All planning and research must take into account the very widely varying technical sophistication and needs of different stakeholders (including large and small, different sub-sectors, etc.)
13. The wide geographic distribution of stakeholders may suggest the use of a "virtual network" method of operation, such as that of the Networks of Centres of Excellence.

# Appendix A: Contacts

# Appendix A: IRC Innovation Study Contacts

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# Appendix B:

# Comparisons of Innovation in Construction to Innovation in Other Sectors

# Appendix B: Comparison of Construction Industry to Other Sectors

| Innovation Factor | Construction Industry | Telecommunications or Manufacturing |
|---|---|---|
| Overall technology leadership | Government is the main player through IRC, NRCan, and CMHC. Academia almost completely uninvolved, and little R&D investment by industry | Industry and academia are the leaders. Government fills "market failure" gap. |
| No. of firms potentially involved in innovation | Many thousands, but a given firm usually involved only with incremental innovations. | Relatively few (<100), a given firm may create significant innovations. |
| Nature of firms | Many SMEs and very small firms. Complex vertical integration of developers/owners, designers, constructors, suppliers, end-users, etc. | Several medium to large firms. Relatively simple industry structure. |
| Nature of innovation | Mainly project-based, highly-individualised and site-specific, with some specific regional needs as well (e.g., far north). Process and systems innovation at least as important as product innovation. Little industrial interest in building performance innovation, especially over life cycle. | Mainly industry-based, much less individualised, and not site-specific. Product innovations relatively more important than in construction. Performance aspects usually very important. |
| Innovation drivers | Cost reduction, ability to win individual bids, ability to sell to end-buyers. Codes also force innovation. Short-term project thinking. | Increased market share, cost reductions. Long-term strategic market view. |
| Innovation inhibitors | Large financial and legal risks, restrictive procurement practices, prescriptive codes, separation of capital and operating budgets of owners/operators, very conservative players. Very low receptor capability in most firms. | Lack of investment capital, market forces, lack of knowledge of university innovations. Some lack of industrial receptor capability, but varies greatly by firm. |
| Dissemination of knowledge about innovation | Poor. Unusual gap between developers, owners, operators, and end-users (who may all be different, or change frequently). Difficulties due to sheer number of players and geographic spread. | Probably much better than in construction, better through technical journals and among players. |
| NRC focus of research | Improved building processes, new materials and products. | New materials and products, some basic physics. |
| NRC research agenda | IRC works across the board for entire industry. | NRC often works on firm-specific projects. |
| NRC geographic focus | Canada-wide, with a few regional technologies. | Clusters—strong local centres of expertise (e.g., Ottawa, Montreal) |

| Innovation Factor | Construction Industry | Telecommunications or Manufacturing |
|---|---|---|
| NRC technology transfer role | Strongly through codes and standards, some through technical journals, access to testing. Increasingly through joint projects with industry. | Has been mainly through technical journals, access to testing, and IRAP. Often through licencing to single companies. Increasingly through joint projects with industry. |
| NRC ability to form consortia | Relatively new NRC thrust, appears to be high although must involve many different stakeholders that include potential competitors, and needs "vertical integration" of players. | Similar to construction, except that fewer firms need to be involved, and less vertical integration needed. |
| Science or technology? | Many products and processes are not high-tech, but performance innovations designed through knowledge of underlying science. Individual projects tend to combine science AND technology. | Many products are high-tech themselves. Individual projects tend to be either science OR technology. |

| Innovation Factors | Construction | Manufacturing | Telecomm. | Bio-Tech | Agri-Food |
|---|---|---|---|---|---|
| R&D intensity | Very low | Medium | High | Very high | Low |
| "Technology push" role | Low, except for medium for suppliers and high for codes | Medium | Medium-High | High | Medium |
| "Market pull" role | High | Medium | Low to Medium | High | Low |
| Nature of product | Large, costly, immobile | Small to medium-sized, relatively less expensive, movable. | | | |
| Life cycle of product | Very long lasting | Short to long | Short | Medium to long | Long |
| Industry receptor capability | Large variation by firm, but mainly very low to medium | Low-medium | High | Very high | Low to medium |
| Pace of change | Very slow | Medium | High to very high | High to very high | Low to medium |

| Innovation Factor | Construction Industry | Telecommunications or Manufacturing |
|---|---|---|
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| Innovation Factors | Construction | Manufacturing | Telecomm. | Bio-Tech | Agri-Food |
|---|---|---|---|---|---|
| Relative R&D capital intensity | Very low | Medium | High | Medium, but increasing quickly | Low to Medium |
| Management skills | Varies widely by firm, especially by size | Medium | High | Medium (unique skills needed for growth?) | Medium |
| Labour skills | Medium, but decreasing | Medium | High | High | Medium |
| Role of codes and standards | High | Low to medium | Medium | High | Medium |
| Impact of other sectors | Low to medium | Medium | Low to medium | Medium | Low |
| No. of disciplines in final project | High | Medium | Low to medium | Medium | Low |
| Market distribution | Local, some regional, occasionally international | From local to international | International | International | regional, some national and international |
| Company distribution | Widely dispersed | Some clusters | Dense clusters | Developing, but probably dense clusters | Widely dispersed |
| Who develops standards? | Mainly governments | Mainly firms | Mainly firms | Technical mainly by firms, but safety by government | Mainly governments |
| Size of firms | Mainly small, a few large | Varies widely | A few large, modest number of small | All small, except as allied to multinationals | Medium to large |