NIST GCR 00-791

A RESEARCH AGENDA FOR FIRE PROTECTION ENGINEERING

M. Hurley

NIST

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

NIST GCR 00-791

A RESEARCH AGENDA FOR FIRE PROTECTION ENGINEERING

Prepared for
U.S. Department of Commerce
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

By
M. Hurley
Society of Fire Protection Engineers
Bethesda, MD 20814

June 2000

U. S. Department of Commerce
William M. Daley, Secretary
Technology Administration
Dr. Cheryl L. Shavers, Under Secretary of Commerce for Technology
National Institute of Standards and Technology
Raymond G. Kammer, Director

Notice

This report was prepared for the Building and Fire Research Laboratory of the National Institute of Standards and Technology under grant 60NANB8D0047 number. The statement and conclusions contained in this report are those of the authors and do not necessarily reflect the views of the National Institute of Standards and Technology or the Building and Fire Research Laboratory.

Designing for Fire

Dr John Nutt,
Chair, Fire Code Reform Centre Australia
ex Chair, Ove Arup and Partners

Introduction

My colleagues and I are designers, active in the construction industry in a number of countries. What we want to see and what we need are consistent global standards in design, which are transparent, universal and readily understood. Without this, differences lead to errors and inefficiencies. If the rules are flexible so that innovation is encouraged, then design encourages export and trade in both directions because good design creates a competitive advantage.

To achieve innovation, we need to be at the forefront of our activities. Design firms have to be supported by a professional community where research is encouraged, and where the risks are defined, controlled, and understood. That research has to be incorporated into the regulations and standards so that flexibility permitted while maintaining public safety. That requires participation in the preparation of the regulatory framework to achieve transparent and flexible rules.

Let me tell you a story which illustrates this point. One of our special skills is fire engineering. Our firm works throughout the world. I happen to believe that a proper understanding of fire engineering will bring revolutionary changes to the way buildings are planned, designed, and operated.

> *"I am often asked by governments to demonstrate the benefits of research and I do so by quoting an anecdote which involved fire engineering and my own firm. Margaret Law who headed Fire Engineering in Arups for many years and who will be known to many of you, used Arups to introduce many of her innovative ideas into practice.*
>
> *One such was the 'fire and island' fire protection concept in the design of large non compartmentalized airport terminals. She had developed her ideas when researching on London Heathrow Terminal 3, and with Paula Beaver, her successor at Arups, applied them to Stansted, London's new third airport. When the international competition for Osaka's new airport at Kansai was called, those ideas were incorporated into the winning entry by European architect Renzo Piano whom Arups were assisting as engineers. Clearly good exciting architecture and engineering was an important aspect of achieving success in that competition but inherent in the planning were certain aspects which were unique in our design.*
>
> *I then ask my questioner "Where do you think the steel for the building was manufactured?" Japan is noted for its immense steel production capacity. It was fabricated in the North East of England, and shipped to Japan. Why? Because the*

designers built using techniques with which they were familiar. That suited the British manufacturers. The Japanese steel industry was very good in other ways, but they were not price competitive in the steelwork of the winning competition design. It was the architectural design and the innovative engineering which won the competition, but the real beneficiaries were the steelworkers on Tyneside in the industrial heartland of Britain.

I have experienced that situation throughout my engineering career. The Sydney Opera House was designed by Danish Architect, Jorn Utzon. A million beautiful ceramic tiles clad the roof and were supplied by the Swedish manufacturer Hoganas. British firms supplied steel, Austrian firms, the stage machinery, French firms, the building cranes."

Design is an important tool in the export of a manufacturer's building products. With that underlying thought let me return to the theme of this conference.

Design

The process of design is to prepare for construction the intentions of the project initiator, satisfying the functional, economic, and operational requirements of the user, while meeting the social, safety, health and amenity criteria of the community. The language of design comprises drawings and written specifications. As in all engineering design, there is an appropriate balance struck between economy and risk, social purpose and function. The developer expects value for money, the community requires that its standards are adhered to.

Design Framework

The design framework therefore comprises two parts:

- A statutory part comprising laws, regulations standards and other rules, and
- A contractual part which incorporates planning, cost budgets, design, specifications, schedules, and quality assurance procedures.

The designer has to transmit intentions to many participants in the construction and approval processes, so definitions and meanings must be clear. All sets of construction documents call up other reference documents to avoid ambiguity and avoid the need to repeat commonly used material in many different contracts. Each variation to a standard increases the risk of misunderstandings and errors. Designers want a common set of reference documents which have wide industry usage and acceptance. A common and transparent language is necessary.

Statutory Requirements

The designer has to understand the statutory framework in which work is carried out, and there are two parts to the definition and application of the rules:

- The criteria contained in the regulations, and
- The application and approval process by which compliance is achieved.

From our experience on the variability across national boundaries, the approval process is the most difficult and restrictive.

The suite of rules are the publicly available documents which the community uses to define its requirements, generally to a set of minimum criteria for public health, life safety, and amenity. But it frequently extends beyond that to embrace consumer protection, (as is the case of serviceability criteria in design codes, limitation of deflections and so on), occupational safety and health, sometimes social goals (e.g. access for the disabled, the protection of property in an unknown or undefined manner like in fire regulations), political goals (as for energy efficiency). None of these are inappropriate, but the contents of each part of this hierarchy is often ill defined.

I won't dwell here on the approval process which incorporates accreditation, responsibility, accountability, audit, penalties and compensation provisions, but in many ways compliance with these exerts a greater influence on the designer than the technical criteria because the application of the rules is not what it appears to be.

Hierarchical Framework

The laws, regulations and standards provide a hierarchical structure within which the contract documents of drawings, technical specifications, schedules and bills are produced. Designers need a clear framework.

With the world wide trend towards the adoption of performance based codes, the process will become more confusing unless there is a transparent logical and universal framework in which to operate. Prescriptive and deemed - to - satisfy regulations provide speed and certainty of achieving approval, but have been found to lack flexibility. Their accuracy and applicability will also diminish as buildings change in planning and structural characteristics.

On the other hand, performance criteria defined by stated objectives provide flexibility, and in many instances, significant savings in construction costs. However, lacking a specified compliance path, incorrect validation procedures may be used. The prospect of error is greater. Designers need a logical hierarchical framework so that transparency is brought about. That Five Level Nordic framework is shown and has been adopted in a number of jurisdictions.

The Laws define the national goals of the building regulations - public health, life safety, amenity, social and political goals. The Regulations give a set of functional objectives and compliance procedures.

A typical statement of function might be that for structural performance there should be no collapse, the structure should be serviceable throughout its life, avoiding excessive deflections, having durability and so on; there should be property protection, certainly of a neighbors property, and perhaps of the building itself. What do these statements mean in real terms which designers can use. Performance criteria should provide this, giving for example, the quantified levels of risk.

National standards and Codes provide the deemed-to-satisfy methods, and following the theme of this conference, the loading codes, the material codes would be called up here. These provide the speed and certainty which the designer needs in the majority of designs. But for non-standard situations, an alternative compliance path is required, and for performance regulations, verification methods have to be agreed.

Approval Process

The approval process comprises application, assessment, decision, compliance, dispute resolution, and regulation support. In a changing technical and political world, unless adequate resources are directed to the maintenance of the regulatory framework, it will date and become restrictive and inapplicable.

It is not surprising to observe a great deal of variation in the building regulations, standards and codes of practice of different countries as regulations and standards are influenced by historic connections, local legislature, trading activities and cost of set up and maintenance of the regulatory framework.

Cost Structure of Buildings

There is one more point I wish to make which relates to the commercial environment in which a designer works - the cost of the project. Risk and economy go hand in hand. There are always pressures on the designer to reduce the cost of a building. A good designer achieves that without compromising the other attributes required - safety, functional efficiency, social statements and so on. A study of construction costs shows where the real economies can be achieved. Although these costs relate to Australia, they are more or less applicable elsewhere.

For every $100 which a developer or owner pays for a building, $50 relate to the direct construction cost and $50 to the cost of land and finance in about equal proportion ($25 each). Of the construction cost, $10 relates to the structural frame, $20 to the building envelope, and $20 to building services (electrical reticulation, lighting, air conditioning/heating, and lifts). The greatest savings can result from efficiencies in the time related costs, and in the operating costs of the building services. The latter is not relevant here. If the time from project initiation to delivery can be minimized, there are substantial benefits to be achieved which will exceed the savings resulting from refinements of analysis. The design and approval period is on that critical time line. Time which results from unnecessary complexity of the regulatory or approval process adds significant cost to a project. Therefore the converse applies.

The reduction of costs through refinement of structural analysis is not as cost effective as the economies relating to speed and familiarity. If procedural simplification can be brought about, cost saving will result.

Examples in this category are:

- Clarity of definition to reduce errors or rework
- Shorten familiarization effort and time to adapt from one design jurisdiction to another,
- Keeping the regulations and standards simple and transparency,
- Providing procedures so that alternative compliance paths are acceptable,

- Mutual recognition of other national codes with due account for geographic factors through the adoption of a common global system,
- Mutual accreditation of computer software,
- Consistency of units of measurement.

Innovation and Risk

Fire engineering research has the potential for introducing the greatest changes into the way buildings have been designed.

Innovation is at the very heart of commercial success. Innovation is the injection of creative ideas in a framework of careful risk minimization which is the essential ingredient of excellence. Each successful designer has a personal formula for achieving excellence, but invariably it comprises two parts, a creative part and a systematic procedural part. Without both, a design is unlikely to be successful.

Innovation, by definition, brings new and at times, untried, approaches to a project with greater risk. However, risk cannot be minimized without judgement, judgement cannot be gained without experience, and experience requires the knowledge gained from research and application to projects. Separate the technical issues from the decisions, and little innovation will be achieved. The control of risk is fundamental to innovation. The community is intolerant to failure. Litigation and the judgements of the courts have supported the consumer. Fear of litigation is the greatest deterrent to innovative ideas.

Where public safety is involved, changes have to be carefully introduced. Governments are responsible for the definition of public safety through regulation. As long as regulations are based on subjective judgements, changes will be slow or not at all. Each individual regulator has a wealth of bad experiences based upon poorly understood circumstances.

Funding of Research

In Australia the construction industry spends only 0.13% on research and development to improve its products and productivity. This is not the case in manufacturing or the resource industries. Why is this so little?

In construction, it is difficult for the various sectors of the construction industry to capture the benefits - builders work to defined documents and receive little for technical improvements; consultants who design and specify products also do not; owners are remote from the construction process and few have an understanding of the issues. In the absence of public pressure, there is little specific incentive for governments to give research high priority. The public, which is the ultimate beneficiary, is too far removed from the decision making process.

A recent study in Australia reported by the CSIRO has shown that construction industry savings have greater effect on the Gross Domestic Product than any other industry sector, more than, for example, business services, public administration, or road and rail transport combined. The flow on effect magnifies the savings in the construction industry to achieve a benefit for the whole community of about two and a half times that saving.

The changes in the funding mechanisms which have occurred, not only in Australia, but in other countries, requires that the research organizations themselves have to articulate the case for financial support for their work, and actively seek it from sources who will benefit from it. This paper's intent is to relate fire engineering science to the industry it serves, particularly the construction industry, and give, by way of a case study, a successful example of how industry supported an ambitious fire engineering research program when no obvious or captive sponsor appeared available.

A Case Study of Fire Research Sponsorship

In Australia in the late 1980s, there was political concern about the escalating costs of building construction and the onerous restraints which the building regulations were perceived to impose on all attempts to introduce flexibility into the approvals procedures.

Numerous surveys were conducted which identified many of the blockage points. There are probably parallels between the conditions which existed in Australia, and those which I suspect exist in the USA now. Briefly, the deficiencies were identified as:

- Building Approval procedure problems
- Procedures lacked transparency
- Too many local variations
- Overly bureaucratic
- Restrictive building code
- Too complex for small /medium projects
- Poor funding for updating maintenance.

Fire regulations, constituting 70% of the Building Code of Australia (BCA), were identified as the largest single technical restraint to the cost effective planning of new buildings and the renovation of old buildings.

Building Regulation Review Task Force

A **Building Regulation Review Task Force** (BRR) was established jointly by all Australian governments to improve the building regulations. I was appointed Chairman. It ran for two years and reported in 1991.

Its main recommendations can be summarized as follows:

- Building Regulations should be overseen by a joint government / industry Board Australian Building Codes Board, (ABCB) with an industry Chair
- Adequate funds should be allocated to the preparation and maintenance of an efficient regulatory system, to be raised by a levy on all non-domestic construction,
- Building Control procedures should be improved by:
    - Preparation of a Model Code of Approval,
    - Introduction of Private Certification as an alternative to local government certification,
    - National accreditation of Building Surveyors (Certifiers)

- A Project Insurance Scheme

- A performance based Building Code of Australia
- Fire research to underpin the performance code
- Simplified Housing regulations.

Those recommendations, 19 in all, with the exception of the funding levy, have been implemented.

Australian Building Codes Board (ABCB)

The leadership of the Australian Building Codes Board has been exceptional. It has wide representation, its achievements have been outstanding, it has adopted a cooperative approach with industry, it is well led and staffed, and it has a plan for an orderly change.

The Building Code of Australia has been written in performance format and issued in 1996, being gazetted a year later. It is recognized as an excellent document, and has achieved wide acceptance. The benefits on a national scale are apparent now.

However, without the levy for the maintenance of the ABCB programs, the amount of money available for fire engineering research was limited. Governments looked to industry to commission the necessary work, while industry was looking to government. The restraint to successful improvement was scope and scale. Unfortunately, the construction industry was an ineffective lobbying body. There was therefore no independent champion of the ongoing reform process.

There were three alternatives:

- Do nothing and wait for 20 years,
- Wait for overseas research,
- Establish an industry/government partnership.

Fire Code Reform Centre

It was to overcome this problem and delay that the **Fire Code Reform Centre** was established. The **strategy** behind the foundation and operation of the Fire Code Reform Centre (FCRC) was to bring together all major participants in the fire industry in Australia, and through a **cooperative non-profit effort**, undertake and manage the research to underpin codes and regulations for the industry.

The FCRC has many unique characteristics. It is an independent organization. It undertakes its own fundraising. It is a **partnership** between industry and government, undertaking the best research, and adopting an **engineering approach** to the outcomes. It brings together competing industries like timber, steel and concrete in a common cause.

Researchers, regulators, practitioners, industry groups, fire services, and building owners have taken part in formulating the research program, raising the funds, directing the contracts, and interacting with industry. The strategy has been to focus fire research in Australia on an achievable goal to compensate for the low level of construction industry research, to spend the available funds on gaining the maximum benefit, and to raise funds by approaching selected groups in industry for sponsorship

The group **ran a campaign to promote itself** and its activities. It commissioned a **business plan** with the small amount of funds which it had available. It set out in detail its **research program**. It developed a **work plan**, and **costed the research**. The research organizations committed themselves to forming a **consortium** so as to offer the best available resources in Australian in a non-competitive arrangement.

Funding

The plan costed the input from the researchers at **discounted rates** so that **sponsors** were seeing a commercial benefit not readily achievable by other means. It co-opted industry identities on an **honorary basis**. The consortium received some financial support and pledges from industry on startup, but what was required was a **sponsor of substance** who would underpin the program and permit the establishment of a corporate vehicle. That came from the newly established **Australian Building Codes Board (ABCB)** which was established in 1992 to implement reforms to the **Building Code of Australia**.

The ABCB had a limited amount of funding available which could be directed towards research. The FCRC mounted a campaign to direct that towards fire reform. The Chair of the ABCB came from industry and could see the problem and recognized the potential benefits. He was instrumental in obtaining ABCB support on the condition that substantial support was given by industry. With that pledge, a **fund raising campaign** was launched.

At the 30 June 1999, a total of US $ 3.5 million since inception has been raised. The Government, through the Australian Building Codes Board (ABCB) has contributed US $1.7 million. The FCRC has raised the remainder from other sources, mostly from industry. To date, this has resulted in industry funding of $1 for every $1 contributed by government. Support has taken forms other than cash contributions. The research organizations with whom the contracts have been placed are undertaking the work at discounted rates, because they are universities, other government organizations. One industry research organization is contributing significantly in kind in addition to its cash contributions. The cash value of the total research program, excluding in kind contributions, is budgeted at US $6 million. In addition, the value of the in kind and discounted rate contributions at the completion of the program will be nearly US $2 million.

FCRC Organization

The **Fire Code Reform Centre Ltd.** has been established as a non profit company limited by guarantee. It is controlled by an **honorary Board of Directors** comprising representatives of **Nominating Sponsors**, an independent Chairman, and an invited representative of the fire services. Nominating Sponsors are those who contribute **US $65,000 annually**.

A pragmatic leadership directs the work of the Centre. The Board comprises sponsor's representatives and distinguished industry identities. The Centre is run frugally and tightly controlled. There are one and a half staff - a part time consultant Technical Director and

Business Manager. A Research Supervisory Committee monitors the individual projects and provides a linkage to the commercial and regulatory world.

The FCRC Research Program **commenced in November 1994** and research contracts have been commissioned as funds become available. That **FCRC Research Strategy** was devised to

- Establish a format for a performance BCA,
- Produce Fire Engineering Guidelines which could for the basis for Building Approvals,
- Study special issues relating to Fire Performance of Materials, combustibility, and FRLs,
- Develop the Risk / Cost Methodology to underpin the performance BCA,
- Develop deemed - to - satisfy alternatives to those existing in the BCA,
- Produce a fully engineered Fire Safety Engineering Design Code.

FCRC Quality Assurance

The high quality of the work is maintained by peer review. A Mid-term Review of the overall FCRC Program was carried out by a team of international experts in 1998 and a detailed review of the Risk Assessment project was completed in March 1999. The reviewers, experts in fire research, fire engineering practice and fire codes, came from Australia, USA, Sweden, Canada and Finland.

FCRC Technical Controls

Control of the research contracts is administered by a Part time Technical Director (Mr. Richard Custer), and a full time Business manager (Mr. Claude Eaton). A Research Supervisory Committee contributes to the work on a volunteer basis, and Technical Working Groups are engaged to supervise individual research projects.

FCRC Outcomes

The FCRC program of research has delivered fire engineering science and technology to the Australian Buildings Code Board (ABCB), the regulatory authority, to bring about changes to the Building Code of Australia. (BCA).

Since the new BCA has been written in performance terms in 1997, the **FCRC Fire Engineering Guidelines** have become the preferred method of compliance for industry practitioners and approval authorities. In Australia, as far as can be determined, every major building project has benefited from the use of the FCRC Guidelines to develop cost effective alternatives to the prescriptive requirements of the BCA.

FCRC Shopping Center Research and Testing

Due to the demand and the potential for significant savings at a time of high development activity, a research project was carried out to make recommendations on the fire safety design of low rise large area sprinkled shopping centers. Large scale tests were undertaken and recommendations made . This will be launched soon as a Design Guide.

Substantial benefits of the core program will be delivered progressively. More than 60 preliminary and final reports and journal publications have been produced to date many of which are already available to interested parties. Arrangements are being made to make them available through an international network of fire engineering societies.

FCRC Achievements

The acceptance of the performance-based fire engineering by industry in Australia has been encouraging. The demand for fire engineers has risen dramatically (fifty fold) in the last 5 years as a result of the research, education and training programs, and the recently introduced performance based BCA, all activities closely connected to the work of the FCRC.

The prime objective has been implemented. There is now strong support for Australian projects and services using the technology developed and underpinned by strong research establishments. Australia is helping to shape the next generation of world codes, talented overseas researchers have been attracted to Australia to participate in the programs, and the spirit of innovation is alive and well.

The FCRC Research Plan will deliver a Fire Safety Engineering Design Code in 2001, based upon new research and large scale fire testing and will incorporating best available fire engineering technology.

ABCB - FCRC Cooperation

The close cooperation between the FCRC, the ABCB, and industry provides a mechanism for regulatory change which is firmly founded on practice requirements, while maintaining the current high levels of safety required by the Australia community.

Conclusion

The Centre is unique. As far as we are aware, it represents the only comprehensive, integrated program of applied research in the world specifically directed to the improvement of a nation's prescriptive building regulations and the development of verification procedures of an alternative performance based approach.

Before I conclude I would like to draw your attention to Unifire99, the FCRC organized conference to be held in Sydney next month to maintain the dialogue with industry, and to promote the work of the Centre so as to disseminate knowledge.

The lasting benefit to Australia of doing the work there is that it maintains researchers in universities and research establishments who are at the forefront of fire engineering research, and who are able to support Australian consultants and contractors in the design of innovative buildings at home and overseas.

Ultimately, that will flow through to new products which can be manufactured for export.

Acknowledgments.

The support of the sponsors of the Fire Code Reform Centre Ltd., and the research consortium is gratefully acknowledged. Without their vision and contributions, the fire engineering research program would not have taken place. The principal sponsors have been: the Australian Building Control Board, the National Association of Forest Industries, Standards Australia, the Cement and Concrete Research Association, and the Forest and Wood Products R & D Corporation. Other significant sponsors have been Ove Arup and Partners, ANZ Bank, AMP Investments, BHP Steel, Building Control Commission Victoria, Civil and Civic, James Hardie, Leighton Contractors, NSW Public Works, St Martins Properties, Steel Reinforcing Institute, Tyco Ltd., and Westfield Design and Construction.

The research consortium comprises : BHP Research, Melbourne; CSIRO Division of Building, Construction and Engineering; Scientific Services Laboratory, ACS; University of Technology Sydney; and Victoria University of Technology.