IMPROVED BUILDING ENERGY EFFICIENCY THROUGH INTEGRATED ARCHITECTURE AND ENGINEERING RESEARCH AND EDUCATION

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ABSTRACT

Achieving energy efficient buildings is important to both architects and engineers. Areas of overlap exist in how each profession works towards this common objective, but there are differences that lead to tensions and lost opportunities. One major opportunity is achievement of total building performance. Each profession has different responsibilities, competencies and viewpoints about energy efficiency. This frequently results in contradictory work. Architects generally see energy efficiency in terms of envelope and spatial organization. The engineer sees it in terms of discrete technical systems design. From this basis there is little chance to rise above the limits in each approach, and tap into the considerable potentials for systematic energy efficiency through interdisciplinary research. This tradition of building research has not encouraged integration of either the process or products of building production. In addition to a new research framework, a new relationship among the many building design disciplines is needed. With this, a significant leap forward in building technology can be made. . An alternative approach is outlined in this paper. Innovative applications of advanced technologies are an important part of the approach. Energy has led the way into technological advances over the past decade and will probably continue to be an important driving force for several decades to come

Research has significantly advanced the technology of building components and subcomponents, but the energy efficiency of the total building product has not reached anticipated levels. In addition, many undesirable consequences have surfaced. The "sick building syndrome" is a leading example. Energy management systems and improved control systems have joined under the umbrella concept of "intelligent buildings". This concept can integrate building services, controls, security and communications, but as yet has not had a significant impact on improvement of product efficiency or quality. The traditional paradigm of sequential design of building systems has not measured up to the challenges required for achieving whole building performance. Based on knowledge about innovative applications of advanced technologies to building problems, a Building Engineering and Architectural Research Center is being established at the New Jersey Institute of Technology. It provides a forum for engineering and architectural research interests to work together to advance the state of the art in fundamental and applied technology. Its integration of the traditional issues of: planning, developing, designing, construction, evaluating and occupying buildings appears unique.

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ENERGY AS A DRIVER OF BUILDING TECHNOLOGY CHANGE

Energy has become an important concern in the design and operation of buildings since the 1970's price escalation of non-renewable energy resources. Prior to that time, the design and operation philosophy was to design individual building systems with large margins of tolerance, then use the margins to fit the systems into a complete building. Using this approach, the designer could concentrate on a few issues, treat several others superficially, and completely ignore many. Problems that arose could be straighted out during construction, or accomodated by widening the margins for allowable building operation. Energy costs for operation were considered insignificant. Primary decision criteria lay with lower initial capital costs, not reduced long-term costs. This changed when energy costs rose. They became a very significant item. Over multiple years, they often exceeded other costs. In this situation, owners and lessors began to demand changes in attitude and approach. Issues of life-cycle costs and total building performance became important. Designers began to look for ways to reduce design tolerances and with initial applications significant problems emerged in building systems integration. Designers could no longer rely on loose margins to absorb difficulties in joining building systems. They had to learn to design in a systemic fashion that could account for synergestic properties.

Higher orders of efficiency and innovation were needed in the design of building engineering and architectural systems. More sophisticated envelope and environmental control systems were required. In response, researchers worked to develop more accurate and sophisticated design tools and procedures. While progress has been made, the consequences of early gains have resulted in serious problems. For example, the design of air-tight buildings, and the reduction of ventilation rates has led to a sick-buildings syndrome, an indoor air quality problem that was previously considered unimportant. Additional problems have emerged for individual designers of HVAC, structural, electrical and circulation systems, as each worked to develop its own new criteria for efficient design. The complex relations between systems were not accommodated. Each design profession tended to operate as if the other professions were secondary, and as if those who actually built the building could work out the details. on the site. As each system achieved an arithmetic improvement in performance, the problems between systems grew logarithmically. It was not enough to simply achieve new resource saving criteria for design of each system. Relationships between systems seemed to have an important role in performance.

Reductions in acceptable tolerances for design and subsequent changes in design practices significantly impacted architectural and engineering design. The result has been a more complex building process and product. Greater specification of details has become critical in communicating design intentions. More of the stakeholders in the building process (owners, renters, regulators, financiers, etc.) have demanded a greater role. With greater emphasis on apriori specification and more interests formally involved in the building process, there is reduced possibility for improving the building informally, or through taking advantage of opportunities for redesign or problem resolution on the job-site. More is expected and being required of system and building designers. Responsibility for whole building success is shifting from job captains in the field to designers in offices, but there are problems with this. As decision-making turns from experience-based rules-of-thumb to apriori rational models higher forms of knowledge are required. In other disciplines, this comes from a long history of research and development. The building industry has not had such a history. It must establish one.

The urgent demands on the building industry, to respond to rapid changes in its societal and technological environments, can be seen in the growing acceptance of the importance of research. Building research has begun to assume a central role. Generally this is attributed to the industry seeing the growing importance of new technologies for improving the industry and its products. Some academic institutions have responded with expanded research programs and modified curricula. While research has not traditionally been a significant part of academic design programs, it is now gaining considerable attention. The growing importance of academic involvement in research has stimuated significant debate about the role of technological research in design education. This has created a concern about the trade-offs between scarce financial and human resources needed to teach/learn design and those needed for new involvement with research and technologies. Energy has been a critical issue in the discourse and the beginnings of the transformation towards buildings research as part of the educational process, not justa respectable but critical.

Energy concerns have, in large part, fueled the advancement of building technology over the past 10 or more years. Other important design issues, indirectly associated with energy concerns, have been seen to be important and stimulated advances in building technology, particularly in the choice and uses of materials. An example of this is the recent attention given to daylighting, to reduce lighting and cooling energy costs. Through this experience it became apparent that design decisions had systemic consequences, and more holistic models were required; models that could accommodate issues such as: siting, space planning, materials selection, specifics of the lighting and cooling systems, and fenestration in the same model. Any and all of these can have particular and profound impacts on the comfort, productivity and security of a building and its occupants.

To date, insufficient research has been done with regard to significantly improving the efficiencies of both the processes and products of the building industry. New algorithms and models are needed. There is significant room for improvement of efficiency in both the process and product area of the industry, as well as the usually neglected areas of overlap between the two. Energy is a critical resource and measure in this research.

AN EMERGING NATIONAL NEED FOR BUILDINGS RESEARCH

A great deal of basic and applied research is needed. It should be conducted within a framework that provides a national focus while accommodating local conditions and variations. It needs to include the diverse public and private actors in the building industry. Examining the potentials in advanced technologies applied to buildings provides a timely means to focus research, organize diversity and enrich the definition of progress in the industry.

Assimilation of the concept of high technology into the activities of the building industry will initiate many new ways to conceive, design and construct buildings. This process can be conducted in a way that includes the varied ideas and abilities of the diverse elements in the industry. Energy concerns provide a means to unify this diversity.

Building design, construction, reconstruction and maintenance activities are important to the U.S. They form a complex industry whose processes represent a major sector in the national economy. Products of the sector provide a critical base for operations of all other economic sectors. Buildings support virtually all human activities, be they individual, organizational, local, national or international. The products of the industry are among the most energy and material consumptive of all economic sectors. Many of basic resources must be imported. But, along with the intrinsic importance, comes apparent implicite neglect.

The building sector is a critical sector in any national economy. In the U.S., general construction directly accounts for about 10% of GNP. It indirectly stimulates another 15 to 30% of GNP. Building construction activities account for approximately 75% of construction costs. Using 1977 as an average year, GNP was $1.9 trillion, total construction receipts were $224 billion, and total building construction contracting was about $200 billion. In 1984, building construction grew 15% to about $230 billion. Its rate of inflation tends to outpace that of the general economy, including that for energy. The building construction sector is even more important in most other national economies. It accounts for about 20% of total Japanese GNP. It is responsible for an even higher proportion of Swedish GNP. Both nations have a long history of building research, and are presently developing strategies to export part of their knowledge and products to markets in other industrialized and non-industrialized nations. Both nations have long recognized the importance of the building sector to national well-being.

It is safe to assume that buildings will continue to provide a critical societal resource through furnishing basic shelter for virtually all social, cultural, political and economic activities. The characteristics and properties of buildings are important to human, local, regional and national development. Improved understanding of human health, safety, well-being and productivity increasingly reference qualities of the human living and working environments.

Building design and production is an important element in a complex, technologically-based economic system. Buildings are a critical factor in the current U.S. transition from an industrial-based to a service-based society. Attributes of buildings and spaces are increasingly seen as important factors in productivity and well-being of humans engaged in providing services. There will have to be important transformations in characteristics of buildings to accommodate information-age needs, many of which are just now beginning to be defined. Services now account for over 60% of the U.S. economy. Providing services is at least as technologically demanding, complex, and subject to rapid change as industrial production. Buildings, how they are organized, constructed, and able to adapt to change are critical factors in supporting or denying performance in service-providing organizations. Buildings are becoming more complex, in response to increasingly complex demands of users and regulators. Buildings, using advanced technologies for operation, utilize a wide array of expert systems, while becoming expert systems in their own right. Buildings are increasingly seen by management as co-determinants of economic efficiency and growth. The implications of this for industry are profound. It is unfortunate that there has been little systematic study of the opportunities and problems in this emerging fact.

Buildings are assuming an even more diverse set of roles in a service-based, market-oriented economy than they had in the prior industrial-based economy. A great deal of research needs to be done to upgrade the understanding of these shifts, the role of buildings in them, and how best to respond locally and internationally. As a highly energy/material resource dependent sector, this research could be one of the highest priorities for long-term national well-being.

An important trait of the building sector has been its slowness to use the exciting potentials in advanced technology; an issue that is important, and of growing importance in international competition. Having a capacity to effectively apply technological advances could make the building industry a model of solid and innovative economic activity. One important reason behind the apparant lack of a more integrated building process is the inherently fragmented nature of the building industry. The average size of an architectural firm is ten people. The composition of an average construction firm changes with each job. Because there is a new composition of workers on each job-site, the efficiencies gained in a factory are lost. The learning curve may exist within the people, but not within the organization. With applications of advanced technologies, the industry may be able to develop a novel approach to improving its efficiency yet retain its inherent institutional diversity and adaptability. Modeling the links between information processing and energy uses can provide one beginning towards this end.

Recent research points to the obvious competitive advantage held by international companies that have learned to bridge gaps in levels of technology, and economic development. Building design, production and maintenance is an obvious international market to further this learning. Virtually all nations have a great need for improving the quality of their building stock. Learning to meet this need more efficiently and effectively at the national level provides a strong basis for meeting the even greater international needs. The best current information points to integration as the most probable route for improvement. The industries that have achieved this tend to be leading most national economies.

NEED FOR A SYSTEMATIC NATIONAL APPROACH TO BUILDINGS RESEARCH

Several research centers and sponsors of research have begun to address the need for integrated buildings research and education. Signs of progress are seen in the collaborative work of such organizations as ARCC (Architectural Research Center Collaborative). Forty schools of architecture are joined to set and carry out building research agendas. The Building Research Board at the National Academy of Sciences and the National Institute for Building Sciences provide further leadership in identifying research and issues of concern to the buildings community. The National Science Foundation, in sponsoring national and international building sector workshops has helped clarify the research domain and its national importance. So too has the Congressional Office of Technology Assessment in its work on the role of construction in major economic transformations. In a request to OTA by Congress, construction was listed as one of nine major areas in need of critical analysis. Considerable privately based research is carried out within corporations that have an interest in buildings but this work has been focused on product-specific results.

The National Science Foundation and other institutions have sponsored visits of U.S. building researchers to other national centers. Several of these directly involved energy issues, while others included energy indirectly. One noteworthy result is evidence that, while other national buildings research centers have accomplished a great deal, they have not been able to systematically organize and apply the results. Their work has by and large concentrated on building parts, with little regard for buildings in actual contexts. They have yet to create a conceptual framework for researching buildings so as to integrate the issues from the conceptual stage through design and construction, to the occupants use.

This situation clearly poses a dilemma for the U.S. building design and construction industry. Most highly-industrialized nations have long had buildings research. While their work has not always been very systematic, there generally have been central research establishments for posing research agendas, organizing research, and distributing results. Considerable knowledge gains have been accomplished by each center, but the research results have generally been fragmented. Should the U.S. depend on what information can be garnered or translated from other national efforts in building research? Must it erect tariff barriers against international building products, or should it strive to generate systematic knowledge for improving the performance of the U.S. building industry?

The U.S. has the opportunity to avoid some of the problems found in the other national research centers: fragmented research agendas, lack of implementation of knowledge, and lack of involvement of industry in the research. It is with this in mind that the research center described herein is being proposed.

TOWARDS AN INTEGRATION OF INTERESTS IN THE BUILDING INDUSTRY

Integration of the interests, abilities, and resources of building developers, designers, component manufactures, constructors, users, researchers, and educators can perhaps best be done in an academic setting. A Building Engineering and Architectural Research Center, concerned with issues that cut across traditional problem boundaries, provides a means of integrating traditionally separate problems and disciplines. The potential of the interdisciplinary model is clearly demonstrated in the success of research and development of advanced technologies. The same model holds great promise for dealing with problems in applying advanced technologies to the building industry. Using an interdisciplinary, interorganizational model, public and private resources can be leveraged to advance basic building technology and education. Individual researchers and special interest groups, working in isolation, are not well suited to achieve systematic research with regard to comprehensive ends. A Building Engineering and Architectural Research Center would act as a focus of special interests, and provide a basis to coordinate building research consistent with a national focus on building research and education. Energy concerns were important in laying the foundation for this work. They will continue to be important in constructing a viable superstructure.

Coherent buildings research will need to go well beyond some of the locally-based conflicts between architectural and enginering designers of buildings; such as the most recent disagreement between the two professions in New Jersey. The New Jersey law specifies that only architects can design buildings intended for human habitation. An engineer recently prepared plans and specifications for a a two-story duplex residence for a friend. A Superior Court Judge held that the engineer had indeed violated the law, and was uphelp by the Superior Court of New Jersey. Upon hearing the results, the President of the New Jersey Society of Architect William Brown, Jr. stated:

> "The State statute clearly says that only licensed architects may practice architecture, not engineers. The courts have again upheld the difference betweend the two professions. That means New Jerseyans are assured that buildings primarily intended for human habitation will continue to be designed by licensed architects." ("Appeal Upholds New Jersey Judge: Only Architects Can Design Homes," Rostrum, Volume 1, Number II, June, 1986.)

While there is some merit to the architects case, the engineers may have something to say about changing the decision, if pushed, due to their much greater numbers and greater political strength. The important point is that both sides have missed the potentials in serious collaboration that concentrates on mutual, and very difficult problems in buildings. They will need to eventually move their professional perspective to a higher plane of activity. Conflicts, such as in the New Jersey litigation, tend only to provide long-term fuel for further disintegration of collaboration within the building design process, and thereby the building product. Each profession needs the other. The envelope and mechanical systems need to be designed as interlinked sets. Arguing over who is responsible for what, while is responsible for the whole product and its performance, tends towards more bad investments of scarce human and natural resources. Architects and engineers need each other, and more, to establish a basis for a more desirable future.

THE BUILDING ENGINEERING AND ARCHITECTURAL RESEARCH CENTER

Organization of the Center

The Building Engineering and Architectural Research Center will be located on the NJIT campus, within the city of Newark. Newark is now becoming the site of very significant urban redevelopment and building projects. At the present time, over one and a half billion dollars of construction is underway in Newark. Newark is at the center of the best public and private transportation systems in the nation, yet still has vast tracts of underutilized real estate. NJIT and Newark are at the center of the important Northern New Jersey/New York metropolitan area. This region has traditionally been a center for national industrial and financial activity. It has recently begun to emerge as a prime location for many projects of a significant national scope in real estate development and building construction. It is the location of the headquarters of many corporations that have a deep interest in buildings, or that are concerned about their large buildings portfolios. Both types of organizations have significant research needs. It has been a location of significant interest and experimentation with alternative approaches to energy use in buildings. The PSE & G building is a noteworthy example of this.

A viable research center depends on a strong interactive relationship among academic, private and public sectors. To be successful, the Center needs the support and resources of organizations and individuals anxious to see major advances in the work of the U.S. building industry. The Center is to be a partnership between academicians and practitioners, each of whom bringing their own expertise to bear on solving the problems of the building industry.

Organization of the Research Within the Center

The many interlocking issues and concerns of design, constructing and using a building are organized within the Center via seven Divisions. The Divisions parallel the general stages involved in producing and using a building. Each focuses on a particular set of problems and issues, but each has been articulated in a manner that requires recognition of the role of other Divisions. The matrix on the following page summarizes the Research Divisions, and how each relates to various educational disciplines. The Divisions are problem focused and not discipline focused. This approach has been shown to enhance interdisciplinary problem solving.

Within the structure of the Center, buildings are viewed in three different ways: as means to other ends, as ends in their own rights, and as vehicles for education. Context and Human Factors Divisions, view buildings as means to other economic, socio-organizational, or human ends. Components, Systems, Buildings and Construction Divisions view a building, or buildings, as the end. The Evaluation/Education Division views buildings in a less traditional sense, as a way to give prominence to the critical but often neglected issues of: a)improving research evaluation techniques, b)technology transfer, and b)research utilization and education.

Division Scope and Research Intent

(1) Context Division. Contextual issues involve the real estate and grounded basis for buildings, the permitting processes, feasibility studies, and all decision leading to a build/not-build conclusion. Infra-structure technologies are of critical research importance in this Division. Numerous traditional areas of buildings study belong in this section: land-use planning, cost-benefit analysis, real-estate finance, building economics, building programming, infrastructure planning and engineering, environmental impact assessment, ecological analysis, demographic studies, employment impacts and governmental approval processes. Important here are the social, economic and political factors that make a building either a long-term opportunity, or a problem. The more natural properties of a site, relative to aquifers and water-sheds, have been increasingly important in recent decades. Infrastructures involve the technical and equipment prerequisites for a building, and the essential links to various artificial support systems needed in building operation.

(2) Elements Division. Elements of buildings are the individual parts that are assembled into systems, which, in turn, are assembled into whole buildings. For example, a chiller is an element of the cooling system and a window is an element of the envelope system. The objective of research on elements is to advance the efficiency and efficacy of each element. The objective of research in this division is to provide the best technology to make the best possible buildings. All individual parts of all building types are considered with emphasis on building materials, windows and lighting, mechanical equipment and safety components.

(3) Systems Division. The Systems Division is responsible for research into assembling elements for use in whole buildings. Research in this division is to help in understanding how parts fit together and perform as systems. There are many systems in buildings. In general they fit into the following categories: heating, ventilating and air-conditioning; lighting; power; plumbing; transportation; structure; envelope; fire/smoke control; interiors; communications and security. Each has its own design practices, techniques and unique requirements for research. Research is needed for all systems in all building types. It should include inquiries into all construction

techniques and performance under the wide variation of U.S. weather conditions. It is important to include renovation and retrofit research of old buildings, as well as new buildings.

(4) Whole Buildings Division. Whole Buildings provide the central focus of the Building Engineering and Architectural Research Center activities. Whole Buildings are the central and ultimate object of research and education. While the context domain provides the basis for decisions regarding build or not build any kind of building, whole buildings offer a context for evaluation of characteristics of elements and systems intended for specific application. All projects in the Center will have something to do with whole buildings. The tradition of building research has invested few resources in studying buildings as wholes. The concentration has been on building: siting, real estate, materials, elements, components, systems or users. Seldom are buildings researched in light of the complex relations between the complex parts required to make a building.

(5) Construction Division. Constructing a building, as designed, using specified elements and systems, on a piece of real estate, is the concluding activity in production of a building. As such, the emphasis is on translating plans and design representations into material elements and systems, that provide sound, affordable and quality spaces. The focus of research in construction is to improve the process that turns plans into products. New, and important areas of competence, in addition to those traditionally with architects and civil engineners, have recently emerged in response to new challenges from increased size and complexity in construction projects.

(6) Human Factors Division. Human factors is the Division where buildings are ultimately judged by their ability to satisfy human needs as intended. Often there may be conflicts between various parties involved in a building project, such as: owners, tenants, construction crews and maintenance personnel. Hence, in some instances the problems are more social than physical, but the physical can be an important element of negotiation for the social. A great deal of fruitful research can be done through looking at some organizational problems as socio-technical-spatial systems.

(7) Research Evaluation/Education. A research center must constantly evaluate its product and the changing needs that result from its completion. Self-examination must be regular and seek the involvement and insight of those outside the Center who are affected or interested. The Center aims to explicitly respond to this need through a Research Evaluation/Education Division. This would includes all the outreach activities of the center and provide the link between the individual researcher and the user of the research. It is important that the results of the research lead to better building designs and built environments

that are stimulating and encourage productive uses. The critical way to achieve this is to improve the bridge between the work of the researcher and the building community. Easy communication over this bridge insures that the researcher is working on the right building community problems, and that the research results are in a useful form. The Division provides the focus for transfer of technical knowledge. Research results are converted into educational programs through courses, seminars and workshops involving members of the buildings community. Publications will be handled by this division through newsletters and papers. Individual researchers will be encouraged to publish results in appropriate refereed publications.

SUMMARY

1. At NJIT we have involved all engineering departments and the architecture school in the BEAR Center. This is a commitment by the researchers and administration to the concept of integrated research by multi-disciplinary teams on issues of importance to the design, construction and use of buildings. We believe such a commitment is unique, and not to be found at any other university.

2. There are several research centers outside NJIT BEAR Center that focus on research described herein. It is intended that collaborative relationshps would be established with the existing special centers. The relationships will range from an exchange of information through coordination of research projects to working together on co-funded projects.

3. A viable research center depends on a strong interactive relationship amongst academic, private and public sectors. To be successful, The Center needs the suport and resources of organizations and inviduals anixous to see major advances in the technology of the U.S. building industry. The Center is a partnership between academicians and practitioners. Each brings their own expertise to bear on solving the problems of the building industry. A partner would benefit from involvement in the Center in the following ways:

-Opportunity to leverage an investment in research programs beyond the scope possible by individual partners.

-Opportunities to increase organizational effectiveness by combining individual efforts with those of other organizations and industries.

- Opportunities to engage a large interdisciplinary group of experts in research projects considered important to and approved by the partners.

-Opportunities for industry to experiment with design of products and processes within an academic environment.

- Opportunities to identity, support and help educate students in fields related to engineering and architecture.

4. There are two major routes for active participation by partners in the Building Engineering and Architectural Research Center (BEAR).

-Advisory Board: All partners have membership on the Board. It reviews research and educational programs and their progress. It sets the Center's research agenda, approves projects and reviews research results. The Board also identifies and helps arrange cooperative efforts with off-campus organizations and researchers.

-Project Monitors/Researchers: Partners are encouraged to monitor projects of particular interest on a regular basis. A partner may have a more active involvement in research by supporting one or more Research Associates, working on campus for special projects.

5. The Center provides an integrated response to the many challenges for research, design, development, application and education in building technology. Many synergistic opportunities for new developments in buildings design are created by the activities of the Center. Research and education within the Center is organized to advance knowledge of building technology and design. By considering buildings as interconnected whole systems, the Center seeks new levels of effectiveness and efficiency in building design, construction and use.

6. Energy studies will be one very important issue for the activities of the Center, just as it was the issue which first clarified the need for and opportunities in such an integrated Center.