Defining a Research Agenda for AEC Process/Product Development in 2000 and Beyond

Design and Construction in the Future

As we approach a new millenium, developments in the technological evolution of humankind in the last 100 years are propelling us in many different directions. The advent of computer technology and the rapid computerization of most of our activities have posed significant new research challenges for scientists and professionals. Capital facilities, which comprise buildings and infrastructure, form a significant part of this technological evolution. Buildings and infrastructure require a lot of resources to create and maintain them. Together they create the built environments in which the majority of humans on this planet live their daily lives. What is important for us to realize now is that these built environments may be affecting us more significantly than natural environments, whose study has been lavishly funded. It is of concern that there is no significant and coherent support for scientific research in the design and construction of built environments.

When reviewing the design and construction of built environments, and their evolution, certain trends can be seen to be evolving. These trends classified in various categories include:

Design

1) Project-based global design and construction teams that exist only for the duration of a project
2) Design of custom-manufactured buildings using high-level technologies
3) Design of active buildings that change and adapt to environmental conditions
4) Design of sustainable buildings and urban environments
5) Design for extra-terrestrial sites

Construction

1) Robotic and telerobotic construction of custom-manufactured buildings using high-level technologies
2) On-site manufacturing technologies for building components
3) Telesupervision of construction projects
4) Automated construction of dwellings on site

Materials and Performance

1) Nanoengineering of new building materials
2) Responsive building materials and construction systems
3) Research in the performance of aggregate building systems at all scales
4) Research in predictive behavioral modeling of built environments
5) Research in maintenance costs and life-cycle energy costs

Research Issues Related to the Trends

Computational Modeling

Scientists have conducted extensive research in the computational modeling of the natural environment. However, the computational modeling of the built environment in its multiple aspects is still in its infancy. This is largely an uncharted territory. The research challenge of the next decade is the computational modeling of the built environment at all scales, from individual building components to large cities. This computational modeling of entities and design processes should emphasize functional behavior and design impact over the visualization of the product. This will enable professionals and scientists involved in the design and construction of built environments to computationally create and evaluate their designs based on various considerations.

The modeling of the functional behavior of the built environment, or natural processes that affect the built environment, offers many challenges. New computational models need to be explored that address issues such as: How are loads transferred through a structure? How does fire spread in a building? How do people evacuate a building, or even a city, during an emergency? How is sound propagated in enclosures? How does thermal transfer occur in a large building over a time cycle? How does a city grow? How is wayfinding established in a city? The task of computationally modeling each of these aspects has been addressed by researchers, but much remains to be done.

An expanded conceptual understanding of computational modeling tools has increased the range of options we now have for the computational modeling of the built environment. We have to rethink the nature and behavior of entities and processes considering computational concepts such as virtual computers, distributed processing, parallel computational models, neural networks, genetic algorithms, annealing algorithms, complex adaptive systems, artificial life and emergence. These concepts offer the possibility of new and more effective computational models, thereby setting a research agenda for the next decade.

Other Research Issues Associated with Each of the Identified Trends

Design

1) Project-based global design and construction teams that exist only for the duration of a project: organizational patterns, communication patterns, global resource management, multimedia communication, collaborative decision making
2) Design of custom-manufactured buildings using high-level technologies: storage and retrieval of custom engineering information in knowledge bases, retooling strategies to adapt to different projects
3) Design of active buildings that change and adapt to environmental conditions: mechanical controls to move small and large building components, multi-climate adaptability of built forms

4) Design of sustainable buildings and urban environments: maintenance and life-cycle energy or “emergy” (embodied energy) costs
5) Design for extra-terrestrial sites: revising material properties for extra-terrestrial conditions, design standards for extra terrestrial conditions

Construction

1) Robotic and telerobotic construction of custom-manufactured buildings using high-level technologies: design of high-strength robots to handle large components
2) On-site manufacturing technologies for building components: micro manufacturing plants to create custom components on site
3) Telesupervision of construction projects: augmented reality and multimedia communication systems
4) Automated construction of dwellings on site: mechanics of unfolding and mobile structures

Materials and their Performance

1) Nanoengineering of new building materials: molecular engineering of new building materials
2) Responsive building material and construction systems: active controls and feedback systems to make buildings dynamic and adaptable
3) Research in the performance of aggregate building systems at all scales: empirical and computer modeling, emergent characteristics at macro levels due to micro effects
4) Research in predictive behavioral modeling of built environments: computer modeling of design impacts
5) Research in maintenance costs and life-cycle energy costs: computer models for intermediate and long-term cycles

Prioritized List of Research Areas

The following is a prioritized list of research areas in the design and construction of the built environment:

1) Predictive modeling of the performance of building components and aggregate systems at all levels, from simple assemblies to entire cities and urban regions
2) Environmentally responsive and adaptable building systems and components with active controls
3) Nanoengineering of new building materials especially suited for the space program
4) Physiological impacts of built environments on human life
5) Organization and communication patterns in project-centered design and construction teams that are globally distributed

Potential Impact of Research

Professionals and scientists involved in the design and construction of built environments have long relied on quasi-scientific methods to assess the impact of built environments on human life. The suggested list of prioritized research areas seeks to add rigor to the understanding of the field.

The research suggested can potentially influence the following significant issues:

1) Improvement of the health of humans living in built environments
2) Prevention of the loss of life
3) Utilization of scarce resources, including money, materials and energy
4) Colonization of extra-terrestrial sites

Criteria to Evaluate Research in the Design and Construction of the Built Environment

The criteria used to evaluate research proposals in this area should be the following:

1) Contribution to predictive knowledge
2) Contribution to general scientific knowledge
3) Contribution to enhanced human health
4) Contribution to the conservation of resources (money, materials and energy)
5) Contribution to technological evolution

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The author holds both a professional degree and a Ph.D. in architecture. He is currently a faculty member in the College of Engineering & Architecture at North Dakota State University. He is one of a growing number of professionals conducting independent research in the design and construction of the built environment. With doctoral work focusing on the computational modeling of the design of an auditorium, the author has dealt directly with the computational modeling of the design of a building. The author has developed a design system to design auditoriums that is based on characterizing the design process as an algorithm.

The author was motivated to write this piece to facilitate the creation of a cross-cutting program at NSF to address the design and construction of the built environment. The author recently submitted a research proposal for the NSF CAREER award that focused on the computational modeling of the built environment. The research proposal requested funds to start a research program in the computational modeling of the built environment. At the very outset, it was difficult to find an appropriate program or directorate at NSF to submit the proposal for funding. Finally the Hazard Reduction Program of the Civil and Mechanical Systems Division evaluated the proposal. This was by no means the best group to evaluate the proposal, but then there was no appropriate program or division at NSF to deal with the computational modeling of the built environment. Recently, NSF started the Urban Research Initiatives Program, which was a

cross-cutting program that attempted to address the built environment and its relations to the natural and human environments. Unfortunately this program has been discontinued this year. Currently, a cross-cutting program does not exist at NSF for research in the design and construction of the built environment. The author hopes that the proposed workshop will facilitate the creation of such a program.