Integrating research on new building conceptions in the architectural engineering curriculum: Educational objectives and benefits

Katherine A. Liapi
The University of Texas at Austin

Abstract

The invention of new building conceptions is driven by very specific needs. New forms of deployable structures respond to needs that are often of critical importance: they can provide emergency shelters and hospitals after natural disasters, house traveling exhibits, fairs, and movable theatres, serve as temporary storage facilities, etc. Despite the obvious advantages that existing or new conceptions of deployable building structures can offer, they are rarely addressed in the architectural or architectural engineering curriculum as a distinct class of structures. This paper presents the author’s effort to integrate new research on deployable structures into the Architectural Engineering (ARE) curriculum at the University of Texas at Austin. Emphasis on innovative thinking and interdisciplinary approach in problem solving are anticipated benefits of this effort. In addition, the study of new forms of deployable structures requires the development of skills in geometric configuration and kinematic simulation. Educational objectives and benefits from the integration of such research into the ARE curriculum are discussed, and examples of student projects are included.

Introduction

The invention of new building conceptions is usually driven by specific needs. The urgent need for shelter that occurs after natural disasters, or the need for rapidly erected building structures due to extreme or unusual environmental conditions, such as those existing in the outer space, are some examples. Deployable structures recently attracted the attention of many researchers because of their obvious advantages when speed of transportation and erection are primary considerations (Escrig 1996; Hanaor 2000). A deployable structure is one that can be pre-assembled, relocated to a site, erected and used, then disassembled and moved to another site. Possible applications of deployable structures include emergency shelters and hospitals, traveling exhibits, fairs, movable theatres, temporary storage facilities, shelters in inaccessible places, meteorological stations, etc.

New building conceptions usually emerge from innovative research in building materials
and methods; very often are based on new research developments in areas marginally related to building design or construction (Robin 1996). Tensegrity structures are a special class of tensile structures that are inherently deployable and present unique mechanical properties. Tensegrity structures are self-supported, internally pre-stressed structures, where parts under compression are not in direct contact with one another, but held together by intermediate pre-stressed members. In addition to their possible applications in the deployable building industry, tensegrity structures can offer an alternative to conventional building structures since they can be also used for covering medium scale spaces or for rainwater protection and shading of public or commercial areas. Tensegrity structures, like most types of deployable structures, have attracted the attention of many researchers in the field because they respond to the continuously increasing demand for structures with reduced environmental impact. The investigation of the appropriateness of deployable tensegrity networks for application in building design and construction falls within the author’s areas of research. The study of the geometric configuration, deployability, visualization, and overall design of tensegrity networks are more specific objectives of her research (Liapi, ACADIA 2000).

Despite the promising applications of deployable structures in building design and construction, in the architectural and civil engineering curricula are hardly ever addressed as a distinct class of structures. Significant differences in the conception and design among structures that belong to this class pose problems to their study within the context of architectural engineering. In addition, the geometric configuration and graphical representation of deployable structures, is in general a challenge, since they are usually characterized by geometric complexity and present more than one functional configurations.

An effort has been made to integrate research on deployable structure in general, and tensegrity structures in particular into the curriculum of architectural engineering without any significant change in the course offerings. The manner in which this research has been integrated in the curriculum and the educational objectives and benefits in doing this are described in the following sections.

**Integration of new research in the curriculum**

At the Architectural Engineering program of the University of Texas at Austin, the course *Advanced CAD Systems* is offered as an upper division elective for undergraduate students, and as an architectural engineering/construction management graduate course. The Advanced CAD Systems course, that is developed and taught by the author since 1998, introduces students to Advanced CAD systems and procedures in building design and construction through examples of actual applications, and through a series of class assignments and projects. One of the objectives of the course is to develop students' ability to visualize 3D geometrical systems related to the design and construction of buildings, and to encourage and enable, through assignments, teamwork and interdisciplinary approach.
A class project on the conceptual design of a new deployable structure has replaced one of the three semester projects initially included in the course syllabus. The emphasis of the project is placed on the preliminary investigation of the geometric form of the structure as a result of the mechanism that allows for its motion.

The introduction of the new project has given the opportunity for an extensive class discussion on the features and benefits of deployable building structures. Sustainability, transportability, construction speed and safety are discussed as significant performance parameters in the design and study of new forms of deployable structures. Reference to historical forms of deployable structures, as well as to relevant research conducted in other academic centers and labs is made. Concepts on mechanism design, kinematic behavior and performance of deployable structures, and structural considerations in the design of new deployable structures are introduced. Among the various forms of deployable structures that are discussed, tensegrity structures are introduced and presented as an ideal example of transformable structures in which geometric form, function, material and structural expression are uniquely related to each other.

As a partial requirement for the development of this project students are expected to define a need that justifies the use of a deployable structure, conduct research on performance requirements of existing and desired structures that serve this need, and develop an initial concept and design of a new structure that fulfills these requirements.

The geometric and trigonometric expansion of a building structure is usually the result of the geometric and kinematic characteristics of the mechanism, or method, by which the structures transform in space and time. For a preliminary investigation of a new deployable structures’ form and kinematic behavior advanced geometric configuration and visualization is required. Computer simulation and animation studies can help identify problems in their initial geometric conception. The computer simulation of the motion of the structure and the display of the structure as an animation of moving parts can identify problems in their kinematic conception. It can also assess the effect of the changing geometry of the structure on space definition, building morphology, and functionality. This effort has been documented in an earlier ASEE publication (Liapi 2000).

Renowned engineer and architect Horst Berger, world expert on tensile structures, has already visited the program, and discussed with students their projects. Berger lectured on the design and construction of tensile structures. Prof. Rene Motro, director of the Laboratoire des Tensegrite, at Montpellier, France, and Dr. Ariel Hanaor of the Technion, Israel, have expressed interest in participating. Lectures by renowned visiting scholars are also expected to attract top undergraduate and graduate students.

Student response to this project has been very positive, as manifested by their unusually inventive and sophisticated class projects. At the same time, this project has allowed them to develop excellent skills in advanced computer visualization and kinematic simulation procedures. Course evaluations have been consistently excellent (3.8 out of 4, on the average). Examples of student projects are illustrated in figures 1-4.
Educational objectives and benefits to the students and program

The educational objectives and benefits offered by the introduction of a deployable structure project are discussed in the following sections:

a) Enhance students’ skills in the geometric conception and visualization of structures

The integration of new research on deployable structures in the curriculum builds on the author’s ongoing effort to include a significant amount of geometric topics inherently related to the architectural engineering education into the curriculum at the University of Texas at Austin. Geometry, which used to be among the essential mental tools for the invention and modeling of spatial structures, is given limited attention in most architectural engineering curricula. Taking into account that geometric complexity is a characteristic of most types of deployable structures, the class project on the conceptual design and geometric configuration of a new deployable structure places emphasis on geometry as an important tool in the study of new engineering forms.

A body of knowledge, mainly from Descriptive Geometry, has already been integrated into the instruction of an introductory course to Computer Graphics taught at the junior level. In addition, concepts from Euclidean and non-Euclidean Geometry have already been consolidated into the instruction of a project-based Introduction to Design course, also taught at the junior level (Liapi 2002). In the Advanced CAD Systems course the instruction of innovative digital media is combined with the instruction of advanced geometric concepts relevant to building design. The author has taken advantage of the geometric complexity that characterizes most types of deployable structures, in order to highlight the significance of graphical simulation methods, as well as to strengthen students’ 3D visualization skills. The integration of this semester project, that focuses on the development of new concept for a deployable building, further exposes students to advanced geometric configuration and visualization procedures.

Advanced tools for the study and visualization of complex architectural and structural systems, such as parametric form development and advanced visualization procedures, including kinematic simulations are gradually added to the material covered by the course. In addition, students are introduced to new research on computer visualization methods, and on geometrically changing structures, conducted in academic research centers worldwide.

b) Strengthen interdisciplinary approach to design projects

Deployable structures in general, and tensegrity structures in particular, offer an ideal example, where geometric configuration needs to be studied in conjunction with structural configuration, mechanical behavior, and technological and architectural expression and functionality. Deployable structures in this regard provide an opportunity to integrate
interdisciplinary approach to architectural engineering class projects or assignments.

The introduction of a project that focuses on the design of a deployable structure in the context of the Advanced CAD Systems course, taught at the senior level, exposes students to the need for a holistic approach in the design of certain types of structures. As mentioned earlier, concepts on architectural morphology, mechanism design, kinematic simulation and structural analysis, relevant to the design of deployable structures, are introduced during this course. New research on mechanisms and materials for deployable structures, and construction management issues that support their adoption are also presented to the students. Some of these topics fall within the expertise of other engineering disciplines, and need to be presented by experienced faculty in relevant areas. Ideally, faculty from the Mechanical Engineering department and the Structures program of the Civil Engineering department should present to the students concepts on mechanism design and features of their structural and dynamic analysis. Till now, graduate students from the respective departments have undertaken this duty. Better coordination with faculty from other departments, or programs of engineering, towards joint instruction, and formation of cross disciplinary student teams are anticipated improvements of the course.

c) Encourage undergraduate student involvement in research

Students in the Advanced CAD Systems course become familiar with on the going research on tensegrity structure conducted at UT by visiting the Tensegrity lab, that is located in the same building where most undergraduate courses are taught. During the last three years several scale models of deployable tensegrity structures, that illustrate the path from the conception of an idea to its realization, have been built and displayed in the lab. Students easily draw the connection between course project subject matter and graduate research in this area. As a result, several students displayed interest in getting involved into this research which led to two successful applications for Undergraduate Research Fellowships, granted by the University of Texas at Austin. In addition, four students from underrepresented groups at the University, after taking this class, applied and received funding from TREX and EXCEL programs, both funded by the National Science Foundation and administered by the Equal Opportunity in Engineering program, in order to conduct undergraduate research in relevant areas.

Summary and conclusions

Innovative research on new building conceptions has been integrated in the architectural engineering curriculum at the University of Texas at Austin with no significant change in the course offerings. The quality of student projects, the excellent course evaluations, and the increased interest and involvement of undergraduate students in this area of research prove the success of this effort.

The integration of research on deployable structures in general, best served the following goals:

a) reinstate the role of geometry in the architectural engineering education as a tool for
the invention and design of new forms. More specifically the overall educational goal of this effort was to reintroduce geometry in a systematic manner in the curriculum as a way of gaining insight into the design of innovative building structures. Tensegrity structures have offered an excellent opportunity to familiarize students, at an early stage, with the inter-dependence of structural, geometric and aesthetic problems in architectural design projects;

b) stress the importance of interdisciplinary approach in building design.

This effort also falls within the author’s educational and research goal to explore and include analytic and experimental procedures and visualization methods that address the geometric nature of buildings into the Architectural Engineering curriculum at the University of Texas at Austin, as well as to promote new research towards the invention of innovative building structures.

Acknowledgments

The projects illustrated in the figures have been developed by the following students: Ben Llana (figure 1), Bernado Quiroga (figure 2), Sonia Solt, Rusty Prentice and Casey Wendelburg (figure 3), and Steven Bell (figure 4).

References


KATHERINE A. LIAPI
Katherine Liapi is an Assistant Professor of Architectural Engineering at the University of Texas at Austin.
She holds a Diploma in Arch. Engineering from the National Technical University of Athens, Greece, and a Post-Professional M.Arch, an M.S. and an Interdisciplinary Ph.D. from the University of Texas at Austin.
She has conducted research in the fields of energy conscious design, daylight simulation, computer aided
design, historic preservation, and architectural theory. Her current research interests are in the areas of
light and deployable building structures (tensegrities), 4D CAD applications in design and construction,
and sustainable building design. She is a registered architect in Greece and has worked in Kassel
Germany, Barcelona Spain, Haifa Israel, Krakow Poland, and in Athens Greece. She is the recipient of
numerous awards in architectural competitions. In 1988 her work was selected for the “Biennial
Exhibition of Young European Architects and Artists.” In the last four years she has received 5 teaching
and academic performance awards, including the 2002 UT College of Engineering Excellence in
Engineering Teaching award.

**FIGURES**

**Figure 1:** Expandable walkway based on “origami” art

**Figure 2:** Geodesic dome composed of deployable prismatic units

**Figure 3:** Transportable Display Structure
Figure 4: Movable pavilion for recreational activities