ACADEMIC QUALITY FUND

Final Proposal, FY 2003 – 2004

Application Cover Page

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Project Title: Engineering Assessment of Historical Structures

Abstract of Proposed Project

Professors Dasgupta, Murray, Byard and Silman of Engineering, Arts and Sciences, Historic Preservation, and Architecture, respectively, wish to submit a request for $250,000 to establish, over two years, a collaborative research and education program in the documentation, conservation, and interpretation of historic structures. The areas of interest are: i) engineering analysis; ii) emergency intervention and extended monitoring; iii) field study and site testing; iv) archiving, searching, and sharing primary resources; and v) undergraduate learning, graduate training, and pre-college instruction. An integrated and global approach focused on key case studies will address the multiple, complex problems facing humanity's endangered legacy of historic structures.

Conventional National Science Foundation funding is available only to consider modern structures where all geometrical and material properties are known; even stochastic characterizations are based on *a priori* specifications. In this analysis the geological materials and the quality of non-standard constructions need *a posteriori* identification of system parameters based on observed results of settlements, cracks, and failures of structural components. A strong background in archeological and sociological developments plays a key role in this novel engineering approach that employs fuzzy logic and Bayesian updating to include historical knowledge in engineering stress analyses. Once this core technology is established, government and private sources are anticipated to sustain the program.

This grant will encourage efforts for scientific, technological, and humanistic interaction where relatively modest resources will have the greatest impact, leverage existing facilities and expertise, and help secure significant support of international scientific research, fieldwork, and student learning.

Engineering Assessment of Historical Structures

Introduction

This multi-disciplinary proposal links research and education in engineering and liberal arts in order to gather, develop, analyze, and deliver technologies, methods, and resources through a combination of fieldwork and university studies. A fundamental objective is to provide undergraduate and graduate students with opportunities to participate with faculty and staff experts on projects that address the real problems of understanding the historic built environment while accounting for the diverse cultural circumstances of each monument. These "contexts for learning" bring together the combined facilities and resources of the Engineering School, the Media Center for Art History, Archaeology, and Historic Preservation, and the Historic Preservation Architectural Conservation Laboratory. This group represents three isolated concentrations within the university and forms a new area of study. The collaborative activities include fieldwork, laboratory research, workshops, courses, graduate programs, doctoral research and an international symposium.

Our model is a project on Beauvais Cathedral that was begun with a grant from the Samuel H. Kress Foundation (via the World Monuments Fund). We used a point–cloud laser scanner from Computer Science to gather 150 scans with one million points each. This data must be processed with Columbia-developed algorithms and then used along with 4,000 digital photographs as the basis for a highly accurate three-dimensional model.

In this research we will study the structural flaws that led to two previous collapses (and now possibly a third) in this great work of architecture now listed as one of the world's endangered monuments. The study will support an engineering doctoral candidate whose techniques and results will be published in peer reviewed journals. In a proposed Columbia-sponsored conference planned for 2003 (Mathews Lecture), we hope to answer the specific question whether Beauvais Cathedral's retrofit is beyond the needs – the answer requires a thorough structural analysis and formulation of refined techniques.

The development of a special purpose stress analysis software for historical structures is essential. Existing computer codes take into account only specified predetermined variables, e.g., member sizes, material properties, load combinations, and seismic response spectra. Those programs are particularly suited to carry out short term dynamic modal analysis and time history response calculations. The user interfaces necessitate the engineer's analysis and design process in the essential models. Fuzzy logic with Bayesian updating will estimate structural dimensions and constitutive properties since no precise knowledge of these crucial parameters is available in historical records. Quasi-static creep response over a long time period will capture large deformations that may cause future damage.

Graphic interfaces will be provided with a focus on developing a common language, design process and useful technologies for diverse groups of users from a wide range of academic disciplines with varied levels of backgrounds. Current communications with Palermo, Italy, and Bangkok, Thailand, address such issues.

During 2002, 2003, and 2004, the Media Center for Art History, Archaeology, and Historic Preservation will organize field programs in the summers and inter-sessions lasting two to six weeks for groups of eight to sixteen undergraduate and graduate students. These "field schools" will be selected from among those already proposed for England (Natalie Kampen), France (Stephen Murray), Italy (Clemente Marconi), Turkey (Holger Klein), and Yemen (Pamela Jerome) and under consideration for China, Cyprus, and the USA, especially from New York City.

Each field program will include one or more scientific or technology partners as part of the research and education process e.g., engineering, computer science, chemistry, earth sciences. Art History and Archæology Professor Stephen Murray has received approval for the first of these from the Office of Continuing Education to begin the regional study of medieval architecture in France next summer. The *Fondation Bourbonnais* will provide ample accommodations at the Château de Bostz, ancestral home of the Bourbon princes. In this way, each field project will rely on existing modest facilities gauged to limited immediate needs — most often provided by an interested sponsor.

The purpose of these activities is to gather scientific and cultural data while developing and testing digital techniques and standards. Credit will be offered through a 4000–level course. While tuition and fees of $3,600 to $3,800 per six-week session will provide basic support, it will not sustain initial investment in equipment, software, technical assistance, network connections, and transportation essential to conduct intensive field recording and analysis. Digital still and video cameras, notebook computers, hand-held devices (PDAs), and measuring tools for use by students will make up a mobile unit that can be used in the field, laboratory, studio, or classroom. Working in conjunction with the Avery Architectural and Fine Arts Library we will archive, search, and retrieve this kind of complex information for use in studying the building away from the site.

Finally, this web-based project will meet the needs of a series of new online architectural history `e-seminars` developed with Columbia-DKV, a graduate certificate program for art history media development and theory, and a Master of Arts in the history of architecture. Students enrolled in the graduate program can help expand the online program as interns. Some will want to write a traditional thesis while others will produce media projects around particular architects, monuments, collections, or ideas.

We anticipate creating online courses, such as a certificate in archaeology and architectural conservation to be developed with the Columbia Video Network, and units for precollege education with the Columbia University Laboratory School and the Dalton School. This provides the basis for an entirely new way of teaching.

Not everyone can enjoy the great privilege of visiting these extraordinary sites. We should think about ways of making these significant "places of history" available to children and adults via the Internet – capturing the imagination that an historic monument can introduce students to complex ideas from a variety of disciplines. This initiative has an urgent and direct purpose: to study and implement social and scientific solutions for protecting humanity's architectural and environmental heritage and, most importantly, to develop effective channels for cultural communication and, perhaps, understanding among diverse peoples around the globe.

Recent awards to our extended group total over $2.25 million from the National Science Foundation, the National Endowment for the Humanities, and the Samuel H. Kress Foundation (via the World Monuments Fund) and indicate the broad interest in this area, the evolving application of new science and technology, and the recognition of Columbia's growing leadership role in this field.

This joint proposal significantly augments Columbia University's established strengths in the study and protection of international historic buildings and places by constructing innovative new alliances for research and education that involve engineering and liberal arts.

This research grant from the university will be used as the seed contribution to develop projects for external funding from national, international, government and private agencies to support liberal arts disciplines through engineering tools. The following sections highlight various aspects of such unconventional and academically exciting ideas.

Engineering Assessment of Historical Structures

Specific Tasks

During the two-year project the team will focus on the following objectives:

1. Assessment of Columbia's global resources and opportunities in cross-disciplinary research and education on the documentation, conservation, and interpretation of historic structures and cultural sites and integration of these capabilities within an ongoing, self-sustaining program for faculty, students, professionals, government and private agencies, and the public at large.
2. Completion of a series of field case studies, scientific and technical developments, student teaching and professional training.
3. Engagement with international experts and organizations.
4. Enhancement of civil engineering models now under study by professionals who integrate digital scanning data acquisition with structural analysis.
5. Introduction of engineering concepts in the broadest sense into the Columbia College Core Curriculum.
6. Expansion of graduate study in art history and engineering with an emphasis on construction materials of historical importance.
7. Establishment of mechanisms for effective archæological and historic site fieldwork throughout the world.

Continuation of Faculty Research

The members of the team started their research collaborations about three years ago. Their complex expertise, tools, and methods to study, protect, and interpret the physical legacy of historic structures and sites demand marshalling the University's diverse elements that are generally isolated within a particular group, department, or school. The learning process fosters ways to exchange ideas of this history-engineering research and share ideas to develop new technologies, train students, engage professionals, and address the educational needs of the larger community.

Regular meetings of the University Seminar on Historic Monuments and Sites as the context for ongoing dialogue, identification of solutions, and evaluation will furnish an effective mechanism. The team will work closely with the seminar's external founding partner, the World Monuments Fund, and the diverse range of faculty who form the core participants. The focus will be to evaluate Columbia's current work, nurture emerging endeavors, and plan for the future.

The particular theme of "structural assessment" will lead to dialogue comprising the full range of issues that affect the documentation, conservation, and interpretation of historic structures and sites. A portion of this grant will be set aside as an *Innovation Matching Fund* that will be used to stimulate new research among the faculty members participating in the University Seminar. The Media center staff will help these projects with project management, identification of matching financial assistance, and coordination with other university and external resources.

Individual members of the team are currently developing proposals to government agencies (European Union, NSF, DoEd, and the NEH), corporations (General Electric, IBM, Palm, and Sony), foundations (Rockefeller, Andrew W. Mellon, William and Flora Hewlett, and Samuel H. Kress), and building an advisory board composed of individuals who share a broad vision and are in a position to support, through grants, Columbia's future work. Tuition from summer and semester field studies will also contribute toward ongoing support.

The team has contacted commercial media, e.g., New York Times—National Geographic Magazine, and HBO, who have expressed interest in educational shows. The principal investigator interacted with the European Educational TV Workshop on this topic via Columbia's Computer Music Center. Any successful contract will enable our university to continue this innovative research.

Global Cooperation

Collaboration with the World Monuments Fund has led to the inclusion of three projects on that organization's *List of Endangered World Monuments*. Those are: the Cathedral of Saint-Pierre (Beauvais, France), the Al-Kaf Family Houses (Tarim, Yemen), and the Church of Zeyrek Camii (Istanbul, Turkey).

At all three sites, field studies with students, conferences and workshops, and scholarly publications have been planned. Other sites of active involvement include the Amheida Excavations (Dakhleh Oasis, Egypt), Frank Lloyd Wright's Fallingwater House (Bear Run, Pennsylvania), and Bourbonnais Romanesque Churches (Besson, France).

Downtown New York is specially suited to be an international venue. One investigator involved with this project directs the firm involved in the structural analysis of several buildings of historic importance including churches. The current exchange program with the University in Palermo, Italy, will permit the team to analyze their work from 2001 summer findings of those historical sites in New York and Brooklyn.

Through partnerships, such as the one with the World Monuments Fund, and a new *Innovation Matching Fund*, the team will encourage an international portfolio of projects and respond to a range of research and study needs. For example, there is no repository of information related to the structural engineering strength properties of construction materials used in historical sites. Theoretical analysis from the engineering mechanics viewpoints will draw international attention to Columbia's civil engineering research. The NSF sponsorship to create an internationally accessible database is within the scope of the Civil Mechanical System Research of the NSF, which supports the current work of the principal investigator.

Currently, a junior faculty member of architecture and town planning division of the University of Palermo, Italy, is conducting research with the principal investigator. The funding from the local government in Sicily, Italy, has been secured. Proposals for the European Common Market, and NATO grants to organize seminars are underway via the offices of Commissione Relazioni Internazionali, Uffcicio Relazioni Internazionali, Università degli Studi di Palermo, Italy.

The engineering interest of the principal investigator led to a cooperation with the engineering dean of the Asia Institute of Technology, Thailand. Computer-based shape analysis, which was developed in conjunction with the Columbia Medical School for biological objects, furnished the software to investigate the shape changes and shape optimization of roofs of Pagodas. The preserved sites in various provinces of Thailand will furnish characteristic damage data for masonry structures. Researchers in building and construction companies in Japan are interested in such historical studies. The leadership of the Dean of Kagawa University, Japan, and his cooperation with the principal investigator on material identification and modeling according to fuzzy logic have drawn international attention. Some findings furnished the background work in an NSF proposal under review.

The educational goal is to link fieldwork with ongoing teaching and research. New information, analysis, and visual materials about the cantilever construction at Fallingwater have been introduced into the online study materials used by students taking the Core Curriculum requirement in art history. Selected undergraduate and graduate students will travel to the sites of the Bourbonnais, initiating an intensive five-year study of 400 twelfth-century parish churches. Their findings will be archived at Columbia University.

Students and experts have been working at Beauvais, Tarim, and Amheida under grants from the Samuel H. Kress Foundation and the NSF. It is now possible for them to exchange data via the internet to activate very sophisticated computer algebra programs. Special statistical packages and graphics rendering tools of *WebMathematica* provide an environment to integrate engineering stress analysis programs with the observed field data.

Engineering Assessment of Historical Structures

Research Applications and Solutions

An essential question posed by this AQF project is how to sustain and share fundamental research developed at Columbia. The answer could be furnished by an example e.g., the particular opportunity to analyze Beauvais Cathedral. The working groups comprise faculty members, graduate assistants, and undergraduate interns. They will employ the most sophisticated contemporary structural analysis computer programs to develop tools and methods for recording, assessing, visualization, and monitoring structural behavior. The results will be published in the internet. Interactive mode of learning will be based on the details captured from field observations. The engineering computation programs will perform on-line quantitative analyses.

While existing facilities will allow the team to function, those by no means are the state-of-the-art coordinated efforts. It is crucial to explore how a combination of existing and improved campus facilities, such as the Architectural Conservation Laboratory in Schermerhorn Extension, located where faculty and students regularly work, can assist to develop long-term and sustaining research.

Student and Professional Education

The seamless interweaving of teaching and research is the hallmark of our university. The team is determined to sustain an educational environment that involves undergraduate and graduate students, mid-career professionals, pre-college students, and the public. This cross-disciplinary project provides unprecedented opportunities. One such example is furnished below.

Blind High School Students

A long-term project pioneered by Professor Emeritus Vreeland of the engineering school won public recognition from the State Government of Connecticut. After his forty years of regular teaching in Columbia Emeritus Associate Dean Vreeland regularly participates in computer graphics projects. His curriculum of engineering drawings for blind students has been unique in the international arena.

As a part of this proposed research the geometrical details of historical monuments and sites will be available in digital form. Dean Vreeland has been teaching middle and high school blind children how to read floor plan views and front and side profiles. The digital images printed and engraved on special paper will provide primary educational materials for liberal arts courses for the blind.

For the first time the blind students will be able to enjoy the historical monuments and artifacts scanned by laser. As more and more partially and totally visually impaired students are mainstreamed, the proposed research and technological development will present cultural history to this community of pre-college students with enormous clarity. The team envisions Columbia to be the unique focal point of such futuristic educational endeavors.

Currently the principal investigator and Dean Vreeland are designing a computer graphics environment that will be open to interact with any multimedia and calculation support including sophisticated algebraic computing systems. To this effect, an undergraduate computer graphics course for civil, mechanical and industrial engineering students was introduced two years ago.

Commercial interest is quite significant to develop and distribute educational materials for the blind. The governments in the Scandinavian countries have been traditional supporters of such research to that sizable community.

Columbia Video Network (CVN)

A convenient vehicle to communicate to a distant student population is provided by the CVN at the engineering school. The new courses will be documented so that videotapes can be distributed worldwide in addition to live classroom teaching. The investigators of this grant will develop in 2003 a team-taught cross-disciplinary advanced undergraduate/graduate 4000-level course on the engineering assessment including documentation, monitoring, and analysis of historic structures.

Columbia Digital KnowledgeVentures (DKV)
Courses of wider appeal will be developed and integrated with the university's digital facilities. These courses will be fundamental to the engineering, art history and archæology majors. The M.S. and professional certificate programs in historic preservation, and a new M.A. in the history of architecture as well as the Ph.D. program in history of art and archæology can be enhanced in cooperation with the Digital Knowledge Ventures (DKV). It is essential to expanded possibilities connected closely with fieldwork, laboratory research, and the University Seminar. The DKV helps to identify professional and mid-career training for engineers, architectural conservators, and construction managers. Furthermore, a novel advanced placement curriculum and teacher support for high schools are anticipated.

Faculty members who participate in the Innovation Matching Fund will be required to help develop segments of these online courses. The intent is to bring together diverse information on historic structures and make it available through a Digital Knowledge Center developed with DKV and distribute professionally tailored knowledge via the internet.

A Sample Course
Some important historical structures are found in and around Columbia. Sample laser scanned images of the Low Library's dome appear in the next page. The geometrical data is fed by Silman Assoc. directly into a finite element program. The calculated responses will be displayed as color plots depicting stresses, strains, displacements and damage if any. Students will be able to analyze such a magnificent structure within the campus.

St. John the Divine Cathedral is another case study. Also, the investigation in New York and Brooklyn by the visiting scholars will be pursued as individual student projects.
Conclusions
The importance of the wider implications of the proposed research program is summarized here. The team envisions Columbia University to be the number one institution in research related to structural characterization of historic buildings. This will bring obvious advantages in our ability to launch further successful grant applications to national and international agencies. This will help cement our ties with the New York architectural community and will, above all, translate the cooperative efforts of the two diverse fields — civil engineering and art history — most positively in undergraduate and graduate programs.

The team is working closely with the World Monuments Watch in its concern with the structural engineering problems of Beauvais Cathedral. This relationship will extend to include in our teaching a variety of yet unexplored historical structures and monuments, as far as ancient villages in Palermo, Italy, and thousand year old Pagodas in Thailand.

Our art history and archæology educational programs will gain most from this proposed research, like the newly-instituted summer field work program, soon to begin its first year of study of Romanesque churches in the Bourbonnais in central France. The Department is about to launch an MA-only in architectural history in which media/computer/engineering studies will play an important role. Civil engineering courses in construction engineering and management of historical facilities will encourage the development of summer and extension programs for undergraduate and graduate credits.

With the NEH and NSF grants Columbia will enhance the ability to provide extraordinary resources for unconventional courses in architectural history with an engineering component. This unusual interdisciplinary constellation of resources and individuals under this AQF will help sustain programs via sponsored research supported by national and international public and private agencies.

The teamwork will provide undergraduates with an engineering outlook within liberal arts courses. Graduate students will be able to cultivate a synthetic view to analyze monuments by examining engineering functionalities. Faculty research will expand on new horizons of qualitative analysis in tandem with quantitative technological advances.