

Part-I

1 Introduction

Information technology provides a versatile conduit to connect classical engineering, modern architecture and construction professions with the legal and civic authorities. The recent attacks on the World Trade Center and the Pentagon made the flow of information from constructed facilities to the disaster mitigation agencies a top priority in multi-disciplinary research. To respond to this unconventional need a multi university research plan is developed to aid the emergency management sectors of local, state and the federal governments. The investment of time and energy of the educational institutions and professionals will be beneficial to the society at large in terms of saving human lives and sophisticated economies.

The new paradigm of *live design* will replace existing CAD type static paradigm by constantly updating the *state of a facility*, e.g., building, bridges, tunnels, airports, with real-time analysis of data from controlling, monitoring and surveillance instrumentation. The *live design* environment will be extendible for incorporating into the evolving architectural drawing any signal of disaster from a new monitoring device that might be developed in the future to respond to emerging needs and changing policies. After the development of the core *live design* technology, universities and industries, who specialize in computer science, civil and environmental engineering, mechanical and reliability analysis, bio-engineering and microelectronics, will be able to create new security related applications and incorporate them seamlessly into the overall design.

Columbia University (CU) will formulate disaster probability algorithms for events of bounded variability with interval arithmetic. The principal investigator and the post-doctoral fellow will facilitate communications between various institutions as the project director and project manager. The Massachusetts Institute of Technology (MIT) researchers will design and fabricate wireless self-powered micro electronic mechanical systems, MEMS, to sense fire and smoke. They will integrate all response data in the electronic representation of a civil engineering design. Carnegie-Mellon University (CMU) will perform basic research and development covering all aspects of computer science. The design pro-

fessionals will guarantee that the proposed enhancements are feasible and the security management system comply with the laws. They will regularly meet with the emergency management officials and will organize annual workshops. Integrated efforts will include: principal component statistical computations with computer algebra and C++, probabilistic modeling with fuzzy logic, formal representation of safety and security information and data exchange protocol written in a markup language to facilitate computer search by content.

The challenge is to *seamlessly integrate* architectural details with monitoring data, subsequently to generate warning statements after processing the complex probabilistic information.

The team will devote resources only on technologies interfacing engineering sciences and needs of rescue authorities, e.g., intelligent signs will be activated by real time warning messages. Standard results from structural stress analysis under wind and earthquake loading will be incorporated without further analysis. The project seeks innovative foreign collaborators who have secured their own funds. Experience in Kagawa of dealing with the Kobe earthquake and Tokyo subway sarin cases can be cited. The lab-on-chip technology of Franche-Comté, could help diagnose individuals who are exposed to chemical or biological agents.

“All dwellers in cities must live with the stubborn fact of annihilation; in New York the fact is somewhat more concentrated because of the concentration of the city itself, and because, of all targets, New York has a certain clear priority. In the mind of whatever perverted dreamer might loose the lightning, New York must hold a steady, irresistible charm. ”

— E. B. White, *Here is New York* , 1945
Urban centers grow denser and more important culturally and economically. This scientific project explores the realm of what is possible to guarantee security. Uncertainty modeling of the most current information will predict extreme events that could endanger peace and prosperity. “We need better technology to get the job done,”

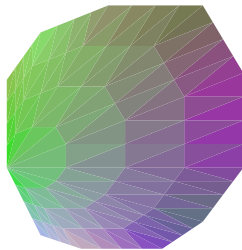
— Governor T. Ridge,
Homeland Security briefing, November 2, 2001.

2 Achieved results from previously NSF research

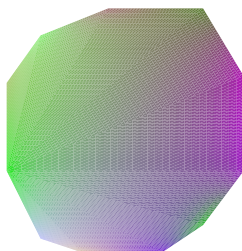
2.1 Columbia University: NSF-6078912

Title: “Convex Polygonal Finite Macroelements”, time: from 8/01/99 to 7/31/01, amount: \$130,000. Related publications are presented in the biography and reference sections.

2.1.1 Digital communication of graphics: smooth interpolation



Triangulation



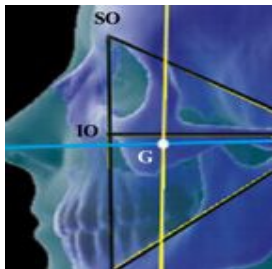
Convex element

Shape functions for convex polygonal finite elements can be constructed in closed form. The derivation, which is based on projective geometry, was discovered by Eugene Wachspress in 1975 [23]. Computer algebra programs have made such shape functions practical. Any convex n -gon finite element can be derived, differentiated and integrated in closed form.

Color interpolation on two dimensional polygons requires only smooth shape functions [13]. Consequently, it is an application of the finite element formulation which is not dependent on integration. Interpolation of color is similar to the interpolation of temperature in Kelvin, since so-called higher order schemes which return negative interior values are not applicable.

Boundary elements are used to approximate finite macroelements numerically. Consequently the smooth closed form formulation can be applied in industrial applications where computer algebra systems are not available. A connection between the finite element formulation and a specific field equation is derived. In monitoring medical images or controlling remote experiments, the algorithm to determine the dynamic anisotropic factor can be codified and then compiled for a web browser, which can launch a boundary element code (e.g. BEASY), to display time series data in color [5].

2.1.2 Principal component analysis: biomedical application

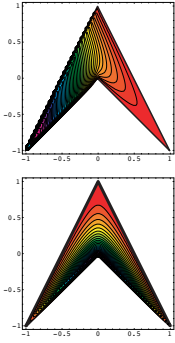


Generated by Jaques Treil

A computational method using finite macroelements has been developed to describe and analyze the human face. A limited data set of orthomorphic sampling points and smooth macroelement shape functions are combined to create a simplified model which can be used to measure the architectural balance between the anatomical components [22]. The nodal locations — landmarks, are universally identifiable references which are routinely extracted from radiological images [7, 19]. The function of the face-jaw system is diagnosed clinically by observing the shape changes associated with these landmarks [18]. Mechanical strain like tensors compare maxillo-facial frame elements and quantify their differences.

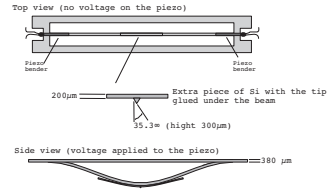
The model based on the landmarks discovered by Dr. Treil has now become a standard reference for scientists and medical practitioners [21, 11, 14]. Unfortunately, finite macroelements are not equipped to account for the concavity present in many maxillo-facial measurements. Approximate methods are applied instead to begin quantify how and whether concavity is as germane to biological function as it appears to be. *Mathematica* programs are included with the article.

2.1.3 Concavity and micro-electronic components



A smooth shape function for concave finite elements which can model the transition between concavity and convexity was developed by the Post Doctoral Fellow [17]. An application of such finite elements is the analysis of microelectronic components. Development of testing of remote monitoring of nano-scale experimentation and instrumentation is developed at the Laboratoire d'Optique P. M. Duffieux Besançon, France [1, 24].

Continuous displacement and stress information can be transmitted efficiently by transmitting only shape function and nodal change information. This limited data set is possible only with concave shape functions and zero-locking stress formulations [20].



These micro-mechanical devices are designed to measure the deformation of skin. Concavity is inherent to the design of the system and the number of available measurement points are very limited. With integrable and flexible concave and convex macroelement shape function formulation the nodal connections within a mesh can be defined by geometry and not be limited by an arbitrary triangular, quadrilateral or hexahedral requirement. Since such a mesh would follow geometry and allow for the indentations associated with large deformation no re-meshing would be required.

2.2 Carnegie Mellon University: NSF-ITR 0113919

Co-Principal Investigator Klaus Sutner is the Principal Investigator of a CMU project, funded by an NSF-ITR grant, to design and implement a system that will store, organize, index and make searchable academic course content, and preserve that content reliably over long periods of time. A central component of the system is an XML based course model that supports both content and presentation markup. One of the primary goals of the project is to deal with highly technical course content encountered in mathematics and the sciences. Mathematical expressions, for example, must be presented in an executable format, so that, say, an integral, can be sent to a computer algebra system for evaluation. Likewise, assertions and proofs have to be presented in a way that enables the use of proof checkers. On a larger scale, the conceptual structure of a document is captured in terms of a dependency graph that makes it possible for the user to navigate the document in a content-dependent fashion.

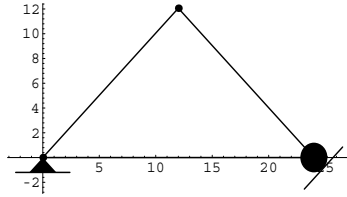
3 Achieved results from background research

The proposed researchers are experts in data representation, programming languages, monitors and signal processing; and construction, architecture and law professionals. Each brings a necessary technology and perspective to the effective development and implementation of the proposed core technology: Live Design.

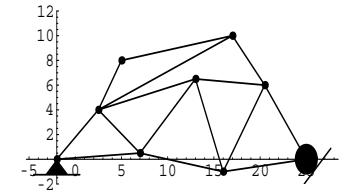
3.1 Interval arithmetic: Columbia University

Probabilistic spatial modeling is a natural extension to high-quality spatial modeling. Higher order perturbations are less useful if the spatial modeling is too discrete. The stochastic system variables (pertaining to the geometry and constitutive properties for a structure, e.g. bridge, aircraft, etc.) invariably enter into the response solutions. Conventional probability analysis is performed primarily with Gaussian distributions. For spatial events probability with bounded variables is more realistic, also temporal events necessarily occur in a semi-infinite domain ($0 \rightarrow \infty$). Consequently, β and γ distributions have been applied to study material and load distributions for structural mechanics.

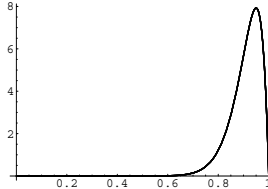
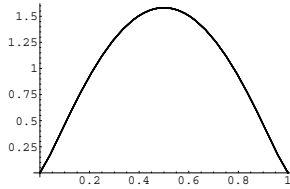
Extensive computer algebra codes have been developed. They convert various distributions and integrate linear algebra procedures to yield covariances of a divergent range of uncertainties.



Three noded truss displacements solved using interval arithmetic



Interval arithmetic method can be extended to a larger more complicated truss



The nature of the β distribution, examples left, determines the level of uncertainty of the outcome. A wide distribution has a higher uncertainty. Conversely, a thin distribution has a lower uncertainty.

Interval arithmetic solves for the bounded behavior of system given the minimum and maximum possible input values [10]. *Mathematica* programs which incorporate interval arithmetic have been completed. The analysis of the truss, see figure left, is performed using this computer algebra [9]. The crown height is given between .9 and 1.01 feet. The resulting tensions, due to a 1 Kip downward force at the crown would then lie in the following ranges:

Interval[-21.8836, 15.621], Interval[-856.996, -568.572], Interval[-805.034, -617.438]

These results apply to the horizontal member, the inclined member and the roller connected member respectively. This calculation can be extended to predict the stress range within a any size truss.

Similarly the series and parallel truss structure can model more abe struct even n -dimensional systems [15]. The form of the stiffness matrix to the stress calculation within the truss is the same as the correlation matrix is to a system of cross connected probabilities [9].

3.2 Structured archiving: Carnegie Mellon University

Integrated computational environments that combine symbolic and numeric computation, visualization, and structured archiving of data hold great promise for future research in many areas of computer science and mathematics. Sutner is the principal author of *automata*, system that facilitates research in automata theory, see “The Size of Power Automata”, in *Mathematical Foundations of CS*, J. Sgall, Ales Pultr, Petr Kolman, eds., SLNCS 2136 (2001) 666–677, and “ σ -Automata and Chebyshev-Polynomials”, *Theoretical Computer Science*, 230 (2000) 49–73, for recent applications of the system. The *automata* package combines general symbolic manipulation, performed by *Mathematica*, a commercial computer algebra system, see wolfram.research.com, with C++ code that speeds up crucial computations. Detailed information about the *automata* system is available at www.cs.cmu.edu/~sutner.

3.3 MIT

3.3.1 Large Scale Distributed Computing

Computer system clusters which support large-scale science and engineering applications and internet infrastructure transactions have been developed. Completed clusters have been distributed to the Department of Energy National Laboratories and Universities. Distributed rendering software for parallel visualization of data sets using massively parallel processor systems and cluster architectures. Software development to assist migration of proprietary analysis databases to a client visualization platform was performed in conjunction with Sandia Laboratories and B.P. Research and development. Design and construction of prototype low cost scalable distributed memory parallel computers has been performed. Basic research has been completed and a micro-scale flow modeling

environment developed which integrates lattice techniques with complex geometric domains from reconstructed confocal microscopy data.

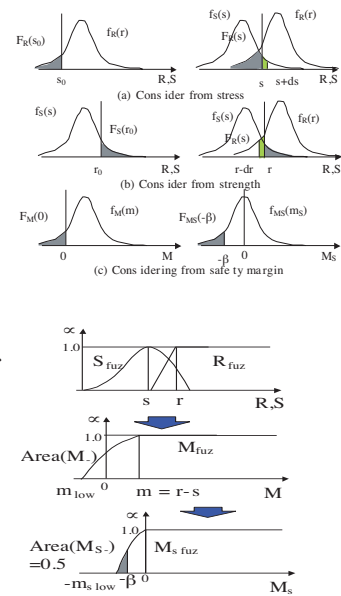
3.3.2 Traffic monitoring

A traffic demand modeling system, DynaMIT, has been under development at the Massachusetts Institute of Technology for the past four years. DynaMIT is a real-time simulation-based system with traffic prediction capabilities. It accepts road surveillance information and generates a summary required for traffic management. It is an integrated system which incorporates behavior models that predict driver relations with the estimate state of the road networks. The predictive information is vital for emergency management, especially information related to evacuation and rescue. DynaMIT is a distributed object oriented software system that is scalable for large and small networks.

3.4 Kobe University

The failures in conventional safety factor design became apparent after the Kobe earthquake. The analytical study of reliability has become the focus of research at Kobe University. This reliability analysis is an essential component of the monitoring of the Tokyo subway system after the sarin attack.

A fuzzy number method was developed for obtaining the relationship between design variables and behavior variables for robust and reliability design. Reliability analysis and reliability based design is a well established field. While it is possible to make reliability estimates on the order of 99%, the correctness of such high reliability figures depends on the distribution used to model the randomness. Higher order estimations depends on the accuracy of the distribution of design variables and the functions which relate these variables. These relationships must be explicit for the combined distribution to be valid. In highly coupled systems such as those modeled by finite elements or boundary elements it is very difficult to obtain this relationship. One established method for obtaining this relationship is Monte Carlo simulation. It is too inefficient for real engineering design [2, 3].



3.5 Professional Experience

Further information is contained in the biography section.

3.5.1 OKG Professional Engineers

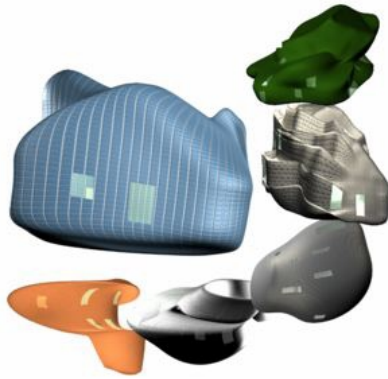
OKG has designed and managed construction of for a number of building and public transportation projects. The most recent is a police building in the watershed north of New York City. Security and monitoring considerations are central to this project. Completed projects include construction work on an Airforce Base in Egypt, the Williamsburg Suspension Bridge and the Holland Tunnel in New York City. Design and construction of structures of this nature require close interaction with government and local authorities.

The firm was established in April 1986 by Dr. Osei K. Gyebi, P.E. who is also its president. Since then, it has experienced a continuing growth in both its human resources and the scope of services it provides. The officers of the firm hold advanced credentials from leading engineering institutions and have established a strong record of professional achievement in their areas of expertise.

OKG offers complete services in the areas of civil, structural, and foundation engineering, mechanical and electrical engineering as well as construction management. In addition, the firm offers comprehensive services in the areas of ventilation and air conditioning (HVAC), as well as environmental engineering. Technical versatility endow the firm with a unique capability to undertake projects of interdisciplinary nature. OKG has participated successfully in a number of joint ventures, and has served as a sub-consultant for projects of an unusual scale. The firm provides non-destructive testing services, ranging from vibration assessment to stress instrument and crack monitoring.

OKG Professional Engineers, P.C. is certified as a Minority Business Enterprise for engineering services by the State of New York, the City of New York.

3.5.2 José I. Sánchez, Architect



The abstract notion of what people like most about their homes is depicted in an animated movie, see screen-shot left.

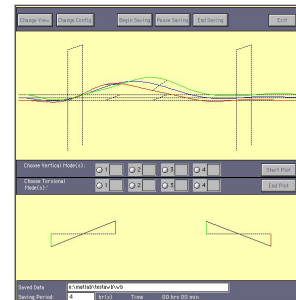
Computer based visualization of an abstract concepts or a concrete buildings require familiarity with rendering tools and the aesthetics of communication.

Both of these examples were realized by the Architect.



3.5.3 Bridge monitoring and data collection, Post Doctoral Fellow

As a database programmer under a contract from the New York City Department of Transportation the post-doctoral fellow designed a database for the to processing of bridge statistics and compute total NYC bridge maintenance costs and staff. She has experience in monitor installation and data retrieval on the New York City Bridges. She supervised the installation of strain gages and the collection of data from monitoring instruments on the Throngs Neck Bridge. She also programmed a visual environment for monitoring the measurements obtained from accelerometers which monitor the vibration of the George Washington Bridge. Bridge engineers will be able to decide if the bridge is safe for traffic depending on the response of the model.



3.5.4 Lawyer

Victor M. Serby is not only a lawyer, he is also a licensed professional engineer. He also invented components of smoke detectors. His legal experience is summarized in the biography section. Currently he is the chair of the New York Academy of Sciences, Engineering Division.

Ms. Tara Helfman will assist. She is a Marshall scholar from New York. She will complete her L.L.M. in Public International Law from University College London.

Part-II

4 *Live Design: a decision support system*

Recent developments in information technology have the potential to support a new civil engineering decision system. This will better enable civic authorities to deal with disasters and threats that can not be anticipated when the building is first constructed. A method to achieve this goal is termed *live design*.

The *live design* environment will maintain a *live blueprint* which can quickly display a threat. Since the system has full knowledge of a building's initial design, and subsequent changes it can quickly generate prevention and rescue strategies.

4.1 *Live blueprint*

A classical civil engineering design is guided by a blueprint, whose electronic counterpart will be called a *live blueprint*, since it is easy to make changes in its specifications. The associated computer programs automatically propagate these changes through the entire system.

Electronic blueprints vs. classical blueprint

Classical blueprint	<i>live blueprint</i>
human intervention	<i>computer searchable</i>
a final document	<i>evolving document</i>
constant data	<i>confidence intervals</i>
large picture file	<i>shorter ASCII file</i>

4.1.1 Comparison with a CAD file

CAD files can be conceived to be the first step of a *live blueprint*. The former can only be searched by matching strings whereas the latter can be searched by the meaning of a technical term ([8, 6, 12]). In a CAD file a location is a fixed coordinate, whereas in the *live blueprint* a range can be specified. This tolerance capability allows probabilistic operations on *live blueprints*.

4.1.2 Strength and sensor data

The electronic form of formalized representation of the complete design specifications will guarantee a flexible and extensible adaptation to changing conditions, e.g., new installations of sen-

sors, new kind of threats, and enactment of a new body of laws. Stress and strain responses from structural engineering analysis, measurements from controlling equipment, security sensor data, and qualitative warning and legal statements from emergency management authorities will be seamlessly integrated to update the *live blueprint*. This improvement over CAD files is possible due to the employment of a markup language. This is explained in §4.2.

4.1.3 Statistical extreme events

Extreme-value events detected by principal statistical combinations will be interpreted as color coded safety strategies and mapped directly onto architectural animations of constructed facilities such as buildings, bridges, airports, tunnels and water and energy conduits. In addition, textual and public address warnings for rescue and evacuation operations will be generated according to the computed probability measures of threatening extreme events. The security database will be continuously updated using the knowledge gained from the observed results.

The core technology for *live design* encompasses diverse disciplines, e.g., engineering, computer science and law. The domain of the latter is clarified below.

Agency	Description
City	Policy makers and law enforcement
Private	Product liability, injury from systems
Federal	Patent issues, proprietary data formats
State	Search and detention, negligence
All	Surveillance: public, private buildings

4.2 LDML, an XML-based Live Design Language

A key component to organize the *live design* information is LDML — *live design* markup language. This special XML document type definition (DTD) which specifies an appropriate collection of meta-data tags, which represent civil engineering concepts, e.g., structural reliability and fatigue, heat resistance and egress. LDML pro-

vides the necessary semantic markup and serves as the main data repository and exchange format between the various components, e.g., civil engineering, safety and security legality, electronic instrumentation and signal processing, probabilistic computations for the confidence level of textual messages. The LDML will help check the legality of future monitoring and surveillance strategies and their deployment possibilities against architectural constraints.

LDML documents are highly complex and temporally evolving structures. When necessary, we will construct the appropriate transformation facilities for input and output.

A significant part of the content of an LDML document will have mathematical meaning. For example, a new stream of thermo-mechanical stress data will require real time recalculation of an evacuation strategy. The presentation environment associated with *live design* system will be accessible to a wide user community without technical background. For example, a web based combination of LDML with Macromedia's Flash technology and IBM's techexplorer, will generate high quality on-screen messages.

Wireless communication of fully marked up data to distant locations will be explored. LDML documents will be generated with the XMLspy editor. Refer to www.xmlspy.com.

4.3 Confidence interval in interval arithmetic

All numerical data in the *live design* specification will be in the form:

$$z = \langle a, b \rangle \quad (1)$$

For example, in *Mathematica* computer mathematics environment, equation (1) is written as: `z=Interval[a,b]`.

The lower and the upper confidence levels are denoted by a and b respectively, $a < z < b$. Interval arithmetic capabilities in symbolic computations have been explored by the principal investigator in [9]. The results of a positive definite system is described in §. 3.1 The correlation matrix is also positive definite and shares the basic commonality with the structural analysis problem coded with *Mathematica*.

4.3.1 β -distribution

For a response z , the bounds a and b and two statistics, i.e., the mean \bar{z} and the standard deviation σ_z define a unique probability distribution as a β - function. Initially the design database will have the mean and the standard deviation of all input signals. The sensor, e.g., a fire MEMS, will run an averaging scheme within a small time window of a few micro seconds to yield the lower and upper readings. All readings will be normalized by $\xi = \frac{z-z_o}{\Delta_z}$ and corresponding $\bar{\xi}$ and σ_ξ are obtained. The manufacturer specifies the range Δ_z and the lower cut-off z_o for all implanted sensors.

A numerical routine constructs the β - probability distribution according to:

$$f_\xi(\xi) = \frac{\xi^{p-1}(1-\xi)^{q-1}}{\beta(m,n)} \quad (2)$$

$$p = \frac{\bar{\xi}(\bar{\xi} - (\bar{\xi})^2 - \sigma_\xi^2)}{\sigma_\xi^2} \quad (3)$$

$$q = p \left(\frac{1}{\bar{\xi}} - 1 \right) \quad (4)$$

4.3.2 Covariance matrix

In a two unit system data from two sensors z_1, z_2 , with frequency functions $f_{\xi_1}(\xi_1)$ and $f_{\xi_2}(\xi_2)$ yields the interval for the (1,2) and (2,1) elements of the correlation matrix $[C]$. The generalization is a network of series and parallel elements with probability measures. Evaluation of a general term C_{ij} in $[C]$ is described in detail in standard text books, *vide* [4].

Eigenvalues of $[C]$ are related to the composite events denoted by the linear combination indicated in their respective eigenvectors. All upper and lower bounds are appropriately suited to the decision making process.

Experience has shown that many commercially available computer programs yield wrong results in computing eigenvalue intervals for very large covariance matrices. In some test cases with 10 inputs some eigenvalue intervals came out to be non-positive. The numerical steps predicted unrealistic combined events where the probability values came out to be negative. In our numerical work we will develop a reliable eigen solver and a Cholesky factorization routine for large

sparse positive definite matrices suitable to predict a combined event of potentially catastrophic nature. This is a research challenge to make *live design* feasible.

4.3.3 Probability of a composite event

The dominant eigenvalues and the corresponding eigenvectors of the covariance matrix $[C]$ are related to the most probable events Z_i , which are combinations of events predicted by z_j . Standard statistical libraries furnish routines to calculate catastrophe probability, $\wp(\tilde{Z})$. These routines are modified to handle intervals of floating point numbers. Thus $\wp(\tilde{Z})$ is represented in terms of a confidence interval. A very wide interval, e.g., .6, would be subjected to further examinations to isolate a case of a false alarm. A high degree of dependability of a warning message could be identified by a narrow interval.

4.3.4 Query security messages

The numerical value of probability of a composite event, $\wp(\tilde{Z})$ in the interval form, as described in of equation (1):

$$\langle a_Z, b_Z \rangle \quad (5)$$

queries a *live design* database to retrieve corresponding text and voice warning messages.

An expression written in LDML is received at appropriate locations and decoded into intelligent evacuation signs, public address announcements, to cell phones and other receivers including remote civic authorities.

Each composite catastrophic event Z_i is associated with the sensor collections $z_j^{(i)}$. Locations surrounding the trajectory of $z_j^{(i)}$ defines zone on architectural animation as affected region in the facility.

4.3.5 Bayesian updating

Recall that a sensor data z_i is used to query the *live design* database to obtain the initial confidence interval as described in equation (1). This is associated with the *a priori probability*. After the computation of all steps through equation (5), we can recalculate the intervals corresponding to the *a posteriori probability*. Bayes' theorem provides a systematic method to carry out

updating using the later. Standard texts describe the classical procedure in detail, *vide* [16, pp 154 – 155].

The *live design* computation uses Bayesian updating using interval arithmetic. This aspect of numerical computation will be developed during the research.

4.4 Computation time

The *live design* system demands different amount of computing time, e.g., almost instantaneous to very long, as encountered in smart signs, three-dimensional animations and large scale simulations.

4.4.1 Real time responses

In a *live design* some results, e.g., a binary alarm signal from a smoke detector, will be instantaneous. MEMS clusters will be processed by dedicated local computers to minimize erroneous smoke and fire warnings.

4.4.2 Short delay in responses

Some extreme event detections will need a pre-determined finite amount of computation. For example, a perturbation scheme to predict the effect of new information input can be analyzed to determine the number of floating point calculations. These will run on a real-time operating system not to exceed a pre-allocated time to complete all operating system functions and retrieval operations. Programs stalling will be avoided to generate immediate security messages within the allowable time constraints. Each sensor data will consist of the RF ID, and no more than four floating point numbers to transmit all information needed for statistical analysis. This compact data-set allows the deployment of sensors to the order of thousand without overloading currently available PCs.

4.4.3 Development time

There are two aspects related to the message database. First, the regulatory text messages will have to be input with context tags in the database. The second phase is to update the probability tags after observing some results.

The *live design* database for fine tuning with Bayesian algorithms will be considerably large.

Symbolic computation, which is convenient to develop concepts for rapid prototyping in an interpretive environment, is too slow to update *live design* databases. After the conceptual development the required numerical steps will be translated into procedural (C or C++) routines to expedite computation by a significant order of magnitude. Translation of symbolic constructs into compiled functions demand considerable time of skilled programming.

4.4.4 Forecasting extreme events

The *live design* system will constantly examine the power set of events. Extreme value statistics are related to p and q in equations (3 and 4). For a group of responses $z_i, i = 1, n$, with all possible (2^n) combinations to detect any plausible extreme event that might have been overlooked. This computation can be run unattended. Highly efficient C++ libraries and distributed computing will be needed to deal with highly time consuming tasks such as eigenvalue computations for matrices containing confidence intervals.

5 A Specific example

The *live design* paradigm will be thoroughly assessed by examining hypothetical office buildings in New York City.

The details of computation and two types of MEMS, for fire and smoke, will be delivered after the completion of the project.

5.1 Core technology development

There are four steps to develop the *live design* environment. First, information on layout, compartmentalization, egresses as well as pressurization to control the spread of fire and smoke, stress analyses, in accordance with the requirements of the NYC Building and Fire Codes is collected. Third, an application then performs uncertainty based numerics where the confidence bounds are expressed as interval arithmetic objects. Fourth, warning messages are generated depending upon the confidence interval of the combined extreme event. These steps will be developed with design specifications and the current state of sig-

nals. An application will perform Bayesian updating of *live design* databases after the event. A generic system will encompass all the four aforementioned criteria.

5.2 Formalizing design with LDML

A markup language for civil engineering design and construction will be used to express all local codes and associated legal requirements for constructing office buildings. The professional engineers expect to extract about fifty pages of regulations written in english for the trained civil engineers. The project manager, Ms Malsch, who is a civil engineer with extensive background in computing and computer science will list the markup tags. A CMU Ph.D. student will design the LDML to represent such semantic assertions.

5.2.1 Markup language

Every month the professional engineers, the architect and the legal team will meet with the policy makers, building and fire commissioners to discuss safety needs that are not properly addressed in the City codes but which are of great concern. Their crucial safety concerns will be incorporated in the *live design* database.

5.2.2 Applications to interface databases

The LDML is merely a representation that facilitates content management. Highly optimized object oriented C++ codes are necessary for efficient execution, extending capabilities in the future and easy maintenance.

During the development, a unix system will run different applications for database query and numerical simulations. Special purpose animation programs, e.g., Maya, are written in proprietary languages. The LDML format will be suitable for data exchange activities across all such applications. Generation of a full electronic version of a *live blue print* test case will be the first test of *live design* applications.

5.2.3 Language and protocol

The LDML and the associated applications will include all necessary tools to perform data exchange tasks. Databases and query programs will be fully documented.

5.3 Uncertainty considerations

A novel aspect in the *live design* paradigm is to consider the probabilistic nature of all input variables that address uncertainties. Bayesian updating maintains the databases by incorporating the most recent information, *vide* [16] and §4.3.5. Subsection §4.3 describes the technic to encompass the confidence level via interval arithmetic.

5.3.1 Finite variability

In most of the structural engineering calculations, Gaussian probabilistic behavior of all uncertain responses are accepted. In conjunction with confidence intervals the principal investigator developed a method to use β -distributions for bounded parameters. Sensor measurements, modulus of elasticity, can be cited to incur errors when viewed to range between $-\infty$ to ∞ . The tail ends are important for extreme events. Gaussian behavior of bounded variables misrepresents extreme values.

In the construction of covariance matrix the current numerical techniques transform all distributions to standard normal ones. This additional step is necessary to reproduce high quality confidence levels for composite events.

Lognormal and γ - distributions have been explored by researchers for time signatures where the time parameter ranges from 0 to ∞ . For responses in MEMS and other sensors semi-infinite domains of stochastic variables are not suitable.

5.3.2 Fuzzy logic

This alternative strategy to the proposed confidence interval based formulation will be explored with the Kagawa University group. They have extensively worked on numerical models and construction applications. They have developed computer programs to calculate reliability index using fuzzy numbers and wavelets and genetic algorithm [2, 3].

A Columbia University Ph.D. student will compare the relative advantages and disadvantages of various mathematical models of uncertainty in civil engineering structural systems.

5.4 MEMS Fabrication

Design, fabrication and implementation of novel wireless micro electrical mechanical systems (MEMS) sensor devices will enable effective system monitoring. MIT will leverage RF (radio frequency) communications to provide wireless data acquisition and locality based inference. Finally, comprehensive characterization of infrastructure scale systems (procedural, IT, policy, response) will be performed with MEMS, which are miniature high-performance sensors and controls that help information systems sense, act and compute. The co-principal investigator J. J. Connor has been teaching an MIT course on the subject.

5.4.1 Annual workshops

The annual workshops will be for two to three days. The first day will be exclusively devoted to familiarize each other's work. The last day will be open to the public, media and the press.

Some international and State issues related to special office structures like the UN, and Empire State buildings will be discussed. The attorney of the team is familiar with the engineering as well as security aspects of the Empire State building where he has his own office.

The meetings will invite professional design engineers from New York City and other large cities with a variety of office buildings. The maintenance engineering staff of embassies, consulates and the UN will describe their safety concerns and successful measures which will be included in the *live design* databases.

(*vide* NY Times, November 13, 2001, pages B-4 and 5 for details on security measures after the AA crash of November 12, 2001)

5.5 Architectural animation

High quality three-dimensional displays will facilitate evacuation training exercise and will play a decisive role with clear depiction of smart exits and egresses. Currently the team uses Maya software in Silicon Graphics machines.

5.5.1 Initial displays

Line drawings will be generated from CAD programs, all such file formats are readable by Maya.

5.5.2 Querying a *live design* database

CMU will develop applications necessary to output optimized information from *live design* databases written in LDML.

Special purpose routines will communicate with the architectural animation programs so that the queried answers are displayed in three-dimensions.

5.5.3 Display of simulated hazards

Different forms of hazards will be distinctly displayed by the intelligent signs. For example, fire hazards and odorless biochemical germs through vents will generate different evacuation and rescue messages.

5.6 Case study — office buildings

All theoretical formulation, instrument fabrication and design calculations will be illustrated with office buildings as examples. Ancillary studies in bridges, tunnels and special buildings like airports will be examined within the context of *live design* databases that are developed for office buildings.

5.6.1 Formalizing design regulations

Relevant sections of the New York City building code will be extracted into a *live design* database. A *live design* markup language meta-tags can be set up. A design *regulation database* will house the design specifications. An application can be written to use this knowledge base. The program can run in a unix environment side by side a structural stress analysis computation. Specification of completed designs can be written in the same protocol. It is then possible to test whether a new design meets the City requirements.

In computer aided design programs, e.g., AutoCAD 2001, input files will be constructed from the *regulation database*. This will help automatize drafting buildings and generate .dxf files. These files can be read in rendering programs, e.g., Maya.

Collections of design specifications written in LDML will be distributed to New York City engineers to test the *live design* development.

5.6.2 Computer networking

As the examples grow from a single office room to a floor and then to an entire office building the computing needs will increase at a more rapid rate. CMU will provide the necessary guidelines and will design conceptual prototypes with the MIT group.

5.6.3 Design simulations

In cooperation with professional engineers and regulatory authorities MIT will select sample case scenarios.

All activities of the *live design* design system will be displayed as high quality Maya animations.

5.6.4 Cooling columns and other primary structural members

Innovative design concepts, such as providing cooling mechanisms within building columns and other primary structural members will be explored. In such engineering solutions the effectiveness of *live design* databases will be examined to comply with cost and architectural constraints.

The team will learn from the on-going studies on the World Trade Center towers. (*vide* NY Times, November 11, 2001, pages B-1 and 11.)

5.6.5 Pressurizing exit passageways and stairwells

Extra air pressure in exits may control the propagation of smoke and fire such that evacuation and rescue is facilitated. We will simulate the actions of pressure sensitive MEMS to control the airflow to develop differential pressure.

Currently battery powered press-sensitive MEMS are available. During first four years MIT will attempt to design and fabricate self-powered wireless pressure-sensitive MEMS.

5.6.6 A single office floor

The preliminary design will initiate with one typical office floor layout in a privately owned multi-story building. The nominal dead and live loads will be directly read from the city building code. Earthquake and wind load spectra will be read

from design handbooks. AutoCAD 2001 will create all line drawings. They will be verified with structural analysis programs which interact with CAD drawings. Single office rooms will be designed automatically using the formal specification written in LDML. City regulatory guidelines for fire and all similar safety measures will be incorporated in the preliminary design from professional experiences. These steps will be formalized in LDML to augment the *live design* database.

Temperature distributions due to simulated fire will be studied. Egress applicability and effectiveness of pressurization will be tested explicitly. The MEMS laboratory responses will be tested and optimal sensor locations will be decided. Methods for detecting man made threats including chemicals and biological germs will be tested within this framework.

5.6.7 Grouping office rooms

The computational complexity when different units are endangered will be examined by the CS students in CMU. The networking capacity demanded to model an entire building will also be predicted.

Cellular automata concept may provide an intuitive scheme to predict the joint effects when two neighboring units catch fires. Fire propagating to closet with chemicals and in the stairways can be quickly predicted by algorithms with predetermined numerical steps of a perturbation scheme.

5.6.8 Exits, stairwells and exit passageways

Critical evacuation and rescue paths during simulations will be displayed in architectural animations with Maya software. Hypothetical situations will involve test cases observed in important buildings.

5.6.9 Suspected chemicals or explosives in garages

The smart signs in upper floors will be tested if the garage sensors observe excessive chemical concentration.

5.6.10 Fire at all exits

Alternative exit strategy through window openings in the lower floors will be provided to add

safety. Collapsible lightweight ladders as a test case will be considered.

The formal specification of the *live design* database will be examined to test adequacy of all safety measures proposed in the simulated test cases.

5.6.11 Demonstration problems

Sources of preprogrammed hazards will be randomly placed in the strategic locations. The closet that houses chemicals should trigger smoke and fire differently from the similar accident in an open office space.

The architect will design signs which lay dormant during normal conditions. In the case of failure of computer controlled signs effects of manual switching by users will be examined.

A scenario will simulate fire in most of the exits. Warning signs not to use those exits will be examined as predicted by the sensors in the exit areas. The corresponding rescue trajectories should appear on the three-dimensional animation of the building at the security command posts. Similar simulations will be repeated for chemical and germ attacks.

5.6.12 Government and private buildings

The legal guidelines for monitoring and surveillance are very different in different office buildings. We shall examine the *live blue print* of office buildings to comply with the regulations. The *live design* database will be checked to correctly caution any inappropriate measure.

5.6.13 Complex security systems

Different technologies are fused in designing versatile safety systems. We shall consider three models of office buildings, a small private, a large government, and a secured building for law enforcement and national security agencies. In addition to sophisticated computer networks MEMS clusters, wireless devices, confidential monitoring systems and other detection systems raise legal and cost issues. Ownership and liability become complex legal issues.

In some of the monthly meetings and in annual workshops members of the Army Corp of Engineers will be invited to bring their expertise

to enrich the *live design* databases with highly specialized security requirements.

5.6.14 International offices

New York City is the home of many important organizations, e.g., consulates and the United Nations, where distinct monitoring and evacuation strategies are warranted. Ms. Tara Helfman, who has a Master of Law degree from London University, UK, will volunteer a month in each year to research on such issues.

As a case study, the lack of a clear United Nations evacuation and rescue program on the November 12, 2001, after an American Airline's crash, will be studied.

The complexity in formulating security databases for foreign and international bodies will be addressed in special seminars organized in cooperation with the Columbia School of Journalism and Columbia School of International and Public Affairs.

The fact that bridges and tunnels may be closed down as security measures, the intelligent evacuation systems of office buildings will be reviewed considering their surroundings.

5.6.15 Citywide rescue measures

The function of any office buildings of the City may be affected by even a distant disaster. The wireless communication technology in addition to dedicated computer network for the emergency authorities will be discussed in the closing report for this application.

5.7 Meeting government agencies

Team members have completed important projects in New York City. They are familiar with the approval process of the regulatory bodies. Team members will meet all level of officials in regularly scheduled meetings.

5.7.1 Monthly meetings

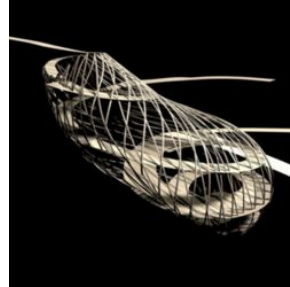
About ten monthly meetings will take place in each year.

Most of the meetings will be attended by New York City officials. New York State and federal officials will be guests.

Details of discussions will be recorded and later written in the LDML terminology so that in the future a computer program can organize information on the basis of content and context.

5.8 An *ad hoc* design challenge

The formal specification of design regulations will be used to examine an innovative concept design called the *geodesic ramp*.



This was randomly selected from a bank of different civil engineering systems suggested by J. Sanchez, the architect of the team.

Typical questions including, but not limited to, the stress distributions will be checked. The formal design specification will be challenged to provide guidelines for tension and compression members curved members in the three-dimensional space. The slab thickness depending on whether it is a ramp in the garage or an evacuation collapsible exit ladder will be queried from the *live design* databases. We shall examine whether there is any legal and regulatory restriction in building the structure depending on whether it is an external or an interior evacuation facility.

5.9 Foreign investigators

The principal investigator has collaborated with Dean Hiroshi Ishikawa of Kagawa University, Japan since 1978 and Dr Tijani Gharbi since 1998. Dean Ishikawa won the international award for introducing probability based information science as a complete undergraduate curriculum. His associate Prof. M. Arakawa has published optimization research based on uncertainty modeled by fuzzy logic. The principal investigator presented symbolic computation based developments in Kagawa and Université de Franche-Comté. Their continuing interactions will focus on the safety and security issues which are equally important to their own research in the current international climate.

5.9.1 Reliability analysis

From Kagawa University, Takamatsu, Japan, Dean H. Ishikawa and Professor M. Arakawa will provide an alternative approach to the probability analysis proposed by the principal investigator in §4.3 and §3.4.1. Their current research on reliability depiction of civil and mechanical

systems via wavelet identification of time signatures and fuzzy logic designation of membership function and genetic algorithm for tracking evolution in time dependent covariance will independently verify the results according to the *live design* methodology of §4.3.3.

In 2001 Dean Ishikawa received the distinguished honor from the International Society of Structural Safety and Reliability for his pioneering practical work. His close cooperation with the Anabuki Construction Corporation will be explored to provide a full scale model where the *live design* methodology could be tested out with the MIT MEMS and Université de Franche-Comté's lab-on-chip.

Specifically, they will provide dynamic response records in buildings during the Kobe earthquake and observed sarin contamination data during the Tokyo subway attack.

5.9.2 Lab-on-chip

The MEMS technology of MIT shares common design concerns with the lab-on-chip technology of Université de Franche-Comté, France. Specifically their efficiency and reliability will be compared in the case of fire.

During the simulation of a chemical or biological germ attacks the toxin density will be predicted and displayed on the architectural animations of the different parts of the building. We will examine whether the lab-on-chip to be mounted on skin can reliably pick up the levels in exposed evacuees.

The applicability of lab-on-chip devices for sensing chemical and biological agents will be assessed. Specifically in a hypothetical situation of a vehicle entering into a public garage with explosives will be assessed using the lab-on-chip capabilities to capture the threat data.

6 Conclusions

In the aftermath of attacks on the World Trade Center and the Pentagon, Information based emergency management requirements have become the central concern in the design of con-

structed facilities. Conventionally, strength based criteria, e.g. dynamic resistance to earthquakes and wind loading, govern designs in which computational activities end with the construction of the civil engineering system. Here an ongoing information processing environment is proposed and a new paradigm of live design is formulated. Design specifications, which are formally represented and written in a content searchable markup language, are maintained and updated during the life time of facilities according to new observations of system performance and government regulations. Based on prior statistics, when a threat is apprehended three-dimensional architectural animations are refreshed and safety messages are communicated to command centers.

A multi-disciplinary university-industry research team will create an open ended computing environment where new threats can be examined to update rescue strategies. This information technology driven project will carry out fundamental research to interlace civil engineering planning, and language design and implementation in computer science. The challenge will be met in cooperation with regulatory agencies, and architects and practising engineering community.

With office buildings as illustrative examples, the research team will deliver a probability based information technology system that guarantees structural safety and improves security. MIT's self-powered, wireless micro electronic mechanical systems to sense fire and smoke will supply realistic signal patterns. Live design databases will comply with legal constraints before suggesting a security measure, such as, surveillance of occupants or decoding proprietary data formats. It is anticipated that after the completion of the project the core idea will attract developers to encompass a variety of complex systems including an entire city block, water and electric supply, communication channels.

The investigators of this proposal found this information technology solicitation to be the only opportunity to venture into such complex, futuristic and exciting engineering research of societal benefit. The team possesses expertise to be convinced that such a mission is attainable now.