AC 2011-2599: A SCALE DYNAMIC MODEL FOR FIRE PROTECTION EDUCATION

Ahmed Cherif Megri, University of Wyoming

Dr. Ahmed Cherif Megri, associate professor of architectural engineering at the University of Wyoming (UW), teaches several HVAC and energy courses. Dr. Megri is also teaching a course titled "Comprehensive Performance of Building Envelope and HVAC Systems" for Summer School at UW, and "Smoke and Fire Dynamics" during summer session at Concordia University, Canada. His research areas include airflow modeling, zonal modeling, energy modeling, and artificial intelligence modeling using the support vector machine learning approach. Prior to his actual position at UW, he was an assistant professor and the director of Architectural Engineering Program at Illinois Institute of Technology (IIT). He was responsible for developing the current architectural engineering undergraduate and master's programs at the Illinois Institute of Technology (IIT). During his stay at IIT, he taught fundamental engineering courses, such as thermodynamics and heat transfer, as well as design courses, such as HVAC, energy, plumbing, fire protection and lighting. Also, he supervise many courses in the frame of interprofessional projects program (IPRO).

In few months, Dr. Megri will defend his "Habilitation" (HDR) degree at Pierre and Marie Curie University - Paris VI, Sorbonne Universities.

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Ahmed Cherif Megri
Associate Professor, amegri@uwyo.edu
University of Wyoming
Civil and Architectural Engineering Department
Laramie, WY, USA

Abstract:

This project was performed in a capstone design course. The objective of this paper is to demonstrate the design and describe the construction process of a 3-D scale model for downtown Chicago. The model will be used to simulate and test the effectiveness of fire defense strategies to address fire or other catastrophes related to public health and safety. The testing is how the students' project will be used by the Chicago Fire Department. This model includes streets, buildings and other detailed information that will help the Chicago Fire Department in planning interventions, considering various scenarios and case studies.

The model has been built in phases, with the overall design incorporating a sophisticated, computer-driven illumination scheme built within the model base, thus allowing the model to be able to display animated scenarios of virtually any depth and focus, by means of time-varying color and brightness. CAD Computer-generated images and laser-cutting methods have been the primary methods of design and construction for the model, but hand craftsmanship is also necessary.

The completed model is fully modular, designed to transport easily between various facilities. The usefulness of the model fulfilled many of the needs of the Chicago Fire Department and City of Chicago as an educational tool within the fire department and for community outreach.

This project included: (1) Identification of the scale, materials, technologies, and strategies for construction; (2) Physical mapping and computer modeling of the downtown built environment; (3) Design of the physical model and computer/electronic components; and (4) Construction of a reduced-area mock-up for final review and approval by the City of Chicago.

1. Introduction

This project was performed at Illinois Institute of Technology (IIT) in a capstone design course and within the framework of an IPRO (interprofessional projects program).

Teamwork, innovation, and complex problem-solving skills make successful professionals - and reflect the overall performance of their organizations. Since 1995, the IPRO team project course at IIT has been teaching students how to excel in the workplace by providing them the practical tools that can make a difference in their professional and personal lives.

The IPRO program joins together students from various academic disciplines to work as a team to tackle a real-world problem. Students from architecture, engineering, and humanities may create low-cost shelter solutions, or chemistry, business, and law students may develop best practices in CO2-reducing technologies. Such experiential learning reinforces traditional education methods, providing students a richer academic experience. For our project, the students were mainly from architecture and different engineering programs: architectural, civil, computer, mechanical, and electrical.

Each IPRO course is organized as a team of 5-15 students from sophomore to graduate level. All projects are designed with goals that can be completed in one semester. However, many projects continue over multiple semesters and years, with continuing areas of investigation. No two semesters are ever alike. An Entrepreneurial IPRO (EnPRO) has the added dimension of business planning and new venture analysis.

- Many corporate and community partners participate in and sponsor projects
- Students, faculty, alumni, and various organizations propose project topics
- Service-learning IPRO projects strive to improve the human condition, K–12 education, and other efforts that make the world a better place
- Sustainability IPRO projects aim to preserve our environmental heritage through exploration of technologies, behaviors, and practices that change our way of thinking, working, and living
- Entrepreneurial IPRO projects (EnPROs) pursue ideas with a business slant

The interprofessional course is an IIT general education requirement. All undergraduates must complete at least two 3-credit IPRO courses. Graduate students are encouraged to enroll in an IPRO project course as well, and may receive elective credit toward their degree.

Scale Models have become the most effective tool used by developers and architects. The objective of this particular project is to design and construct a 3-D, reduced scale model for a portion of downtown Chicago. The model will be used to test and simulate the likely performance of fire defense strategies in case of fire or other catastrophes related to public health. This model includes streets, buildings, and detailed information that help the Chicago Fire Department in intervention, considering various scenarios and case studies.

The model has been built in phases, with the overall design calling for a sophisticated, computer-driven LED illumination scheme built within the model base. The model thus is able to display animated scenarios of virtually any depth and focus, by means of time-varying color and brightness.

The final model is fully adaptable and demountable, and has been designed to transport easily to various facilities. The usefulness of the model thus can be extended to many areas of the Fire Department and city, as an educational tool within the department and for community outreach. CAD Computer-generated images and laser-cutting methods have been primary among techniques used to design the model, but hand assembly has also been a part of the project.
This project includes:

- Identification of the scale, materials (figure 1), technologies, and strategies of construction.
- Physical mapping and computer modeling of the downtown built environment.
- Design of the physical model and computer/electronic components.
- Construction of a reduced-area mock-up for final approval by the City of Chicago.

Figure 1: Material selection and processing (Photo courtesy of Tarek A. Megri)

2. Project Phases

The model project is complex, involving a good degree of materials consumption and labor, and required many disciplines working together to produce a consistent and seamless result. With this in mind, careful planning and consistent progress are paramount to ensure the successful completion of the project.

The following phases have been followed to help ensure the best results of this very exciting project:

Phase I: Research and Design: the team assembled talented members. The members are students recruited mainly via advertisements and interviews with the instructor (the first author of this paper) and the two team leaders (the second and third authors of this paper), in various disciplines. The team leaders are engaged students with very high potential and credibility among faculties and students. The team members concentrated on the following issues of the project:

- Acquaintance with objectives and methodologies.
- Agreement on scale(s) of streets and city blocks within the model.
- Definition of overall construction practice (including rough decisions about materials, technologies, and so forth).
- Electrical engineers investigated the technologies required for the illumination.
- Computer Science students discussed and decided about the computer technologies and I/O interface(s).
- Architects, civil and Architectural engineering engineers established guidelines for physical construction of the individual structures that comprise the main model.
- Other team members performed researches within their respective areas.

Phase II: Mapping / Planning: During this phase, the individual disciplines broke into groups, planed and developed their respective areas:

- Architects, civil and architectural engineering students mapped the city blocks. Standard methodologies for drafting standards, construction techniques, and level of detail were established. CAD drawings for all downtown buildings within the scope of the trial model were created during this time.
- Other disciplines (computer scientists, mechanical and so forth) designed their respective interfaces.
- At the end of this phase, a mock-up proposal was created, and prior to construction of the mock-up, meetings helped between various parties to approve the plans.

Phase III: Construction of a Mock-Up Model

- All team members coordinated to produce the trial mock-up model. First, the mock-up model consisted of mainly the execution of the street system, city blocks, and buildings. The degree of details achieved was depending on the size of the team and project budget, and also primarily the desires of the client. Later, the mock-up demonstrated the full capabilities of the model, with a computer interface and software being developed at this time as well.

3. Model Overview & Physical Features

The main objective of the Downtown Chicago model that it will be used for educational purposes by the Chicago Fire Department, both in use as a means to familiarize employees with the one of the world's most complex urban environments, but also as a dynamic visual aid that will be used to illustrate and simulate computer-generated models of emergencies.

The Chicago Fire Department is the Nation's leading fire department in terms of disaster preparedness and event forecasting. This scale model of downtown Chicago will serve as an invaluable tool in a growing collection of advanced technology employed by the department, and will be a very understandable means to understand complex systems. The Department may also use the model as a means of community outreach, as it can be transported to various meetings with community groups.

The basic concept for the model is a modular, acrylic structure sitting atop a rigid, opaque base. The components of the model are base, streets, city blocks, and buildings. The highlight of the model is an array of multi-colored Light-Emitting Diode (LED) lights built into the base structure, which illuminates the various acrylic features of the model based on input from a computer interface.

These LEDs and computer interface present a powerful tool that can be used for a variety of features. First, they can dynamically demonstrate computerized simulations and predictions of disaster propagation. Second, they are a versatile tool that can be used to educate members of the department on disaster-readiness strategies.

Finally, individual buildings are quickly identified by color in various categories – for example, high risk of terrorist threat, lack of fire protection systems, financial and government institutions, daily population, and so forth. These various combinations are limitless and current at all times, due to the programmable computer interface of the model. As more sophisticated computer models or new concerns arise, the model will be able to adapt to meet these demands.

The model was constructed with the understanding that it is to be a working model for the purposes of the Fire Department. With this in mind, portability, durability, and ease of use were given substantial and adequate consideration during the construction of the model. The Fire Department operates out of many facilities, and it is conceivable that the model will be transported to various locations frequently over the course of its useful life.

Built to a scale that was defined by the research team in consultation with Fire Department, the model provided an adequate level of detail, and ample room for visibility of occurrences happening at street level. Also, this scale allowed sufficient space within the model such that wiring and electronic devices was implemented without extreme difficulty in placement (figure 2).

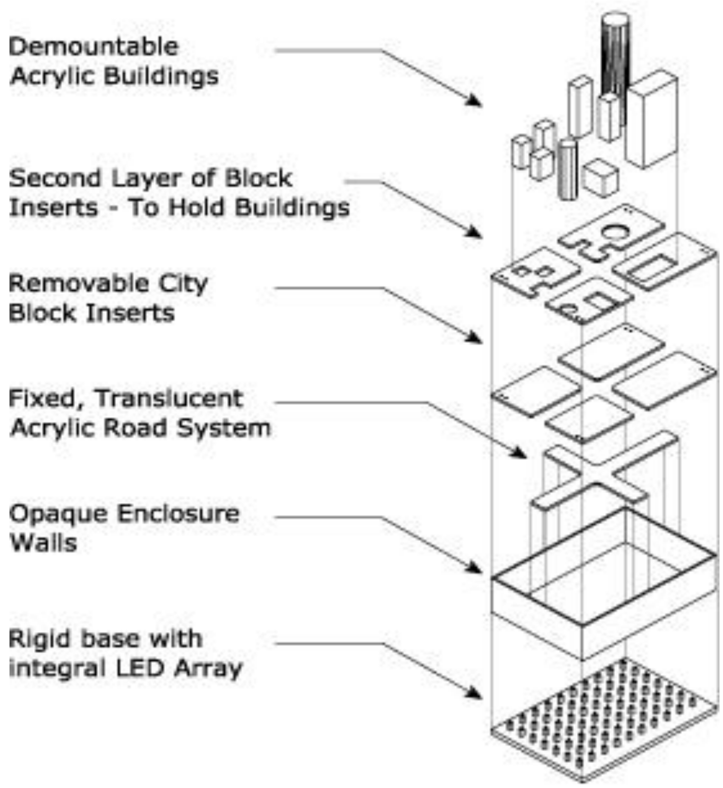

Figure 2: Schematic View of the Model Assembly

Base: the base of the model was constructed of durable wood (aluminum can also be used). The base is entirely opaque at the sides and bottom, so that light from within does not suffer interference or leakage, which would undermine the presentation quality of the model.

Handles was incorporated in each modular part of the model base, so that transportation is facilitated. The project team determined the appropriate sizes for the base of the model and ideal orientation.

Street System: the street system forms the primary organizing and spatial system of the model. As downtown Chicago is a relatively stable and highly built environment, it is not foreseen that any substantial changes to the roadway system will occur during the lifetime of the model. Roads and alleys thus were affixed permanently, and gave order and rigidity to the other elements.

Care was given to the construction of the roadway system. A system of dowels or chairs was devised to raise the roadways off the bottom of the model (flush with the top of the base), to accommodate the LED system within the base. At the same time, these elements are not intrusive to the appearance of the streets when seen from above.
The streets were constructed of sandblasted acrylic, ¼" in thickness or greater. The street names were clearly identified on each street, by etching affixed lettering of another sort.
Block Inserts: the city blocks within the model scope were built to fit within the street and alley system affixed to the model base. The blocks were constructed of double-thick, clear acrylic. The bottom layer is uncut, providing a stable base. The top layer is identical, but has cut-outs to accept the model buildings that are placed on the model. These cut-outs stabilize the buildings and prevent buildings from shifting when the model is in use.

Each block was numbered, according to the city numbering system, and each building on each block was assigned a sub-number. The block number and building sub-number were laser-etched in each space accommodating a specific model building. Chairs or other support for the blocks were devised. These supports were attached physically to the block inserts. Block inserts were fitted with small holes to extract them from the model bases.

Individual Buildings: Individual buildings were constructed of acrylic. The acrylic was laser-cut, and joined together at edges with typical means. Each model building was laser-etched discretely with its assigned block and number, to assist in reassembly of the model after transport. The buildings were designed to fit snugly into the openings provided in each city block. Whenever possible, façade detail was added to each building, to aid in recognition and identification.

4. Proposed Model Uses

The model can be used for *Emergency Forecasting and Management.* The following uses could easily be accommodated with the model structure developed in the proceeding section, although the uses are clearly not limited to those listed here.

Events: multiple events are considered for simulation using the model developed:

- Airborne Terrorism: most likely targets within Chicago lie within the model area.
- Attack on Water Facilities: the primary water facilities for Chicago and many suburbs lie within the model area.
- Biological Weapons: the complex spread of biological weapons could be modeled and better with the LED system. Many hospitals exist with the model area, and these could be considered in the analysis.
- Bomb: these devices would likely be triggered downtown, possibly near mass transit.
- Fire: the spread of flame and / or smoke.
- Large-scale Evacuations: time-varying analysis of evacuation strategies and potential conflicts.

- Utilities: many critical power utilities are within the downtown area, including chillers and power distribution.
- Weather: critical events pertaining to the weather (snow, floods) can be demonstrated and planning considered.

Analysis and Specifics Pertaining to Individual Structures

The analysis of different structures (building in particular) is performed according to the specifics pertaining to individual structures:

- Age: buildings could be shown based on age of fire prevention systems installed, or based on fire code compliance. Key deficiencies could also be highlighted for strategizing.
- Bridges: analysis options could include differing strategies depending on whether bridges are in typical position, or are raised (or otherwise disabled).
- Daily Population
- Financial Institutions
- Fire protection systems
- Height: useful for considering different strategies needed in a given area, especially considering simultaneity of events.
- Mass Transit Stations
- Subterranean Structures
- Terrorist Targets: targets could be divided and highlighted based on risk or terrorism, or based on likely type of action.
- Tourist Locations

5. Construction Techniques & Technological Integration

The project team determined the appropriate construction techniques for creating the model, based primarily on the recommendations outlined above. However, it is understood and anticipated that the project team will develop more refined, specific recommendations during the future researches, and that other ideas can be generate other needed means of construction. At this stage, the team addressed the following construction techniques:

- Materials (figure 1)
- Process for Creating Base
- Process for Creating Block Insets
- Process for Creating Buildings
- Adhesion
- Serviceability

Circuitry: a small circuit was designed and fabricated to control the various LEDs within the model. Typical full-spectrum LEDs are controlled by supplying varied voltages to input leads for Red, Green, and Blue. In the future, there may also be other power requirements, depending on the type of LED chosen for the model.

Computer Interface: the computer interface to the model was configured in distinct layers, similar to the setup of a network protocol. The lowest layer is a direct I/O functionality that communicates raw data to the model through the physical interface.

The second layer is a software interface that translates commands into a direct I/O data stream, and passes this data stream to the raw data interface. This layer is used to execute bulk commands as well, such as control of named groups of LEDs (such as those beneath particular streets), LEDs by row (such as a particular row or column of the basic grid), and so forth.

The final layer is a GUI that allows the user to interact with the model. The GUI allows users to load and save real-time LED schemes from previous sessions, and to import data from third-party software. Import schemes probably are exclusively CSV format to start, but if the Fire Department's software generates real-time data in a particular format, this special format may also be handled natively. The final aspect of the GUI is to send data to lower-level layers in a real-time fashion, so as to produce animations of data on the model (figure 3).

LED Illumination:

General LED Grid: LEDs was placed in the model base in a regular grid, so as to allow for illumination of virtually all areas of the model. The grid was as tightly spaced as possible, provided that constructability of the model is not impaired, and there is no "bleed-over" from individual lights when illuminated within the model. Special care was taken in the design of the model lighting to provide the best clarity and resolution. The design avoided "pinpoint" hotspots of light on the undersides of the acrylic, as these can be distracting.

Directional LEDs with a narrow focus were preferred. The project team fabricated an effective enclosure system that limits the light emission from LEDs to isolated regions (figure 4).

Special Street Illumination: It should be emphasized that the street system is by far the most critical information area within the model. Most simulations rely heavily on the street grid to display tactics and flow. Therefore, extra attention was given to these areas of the model.

Special Address and Street Name Identification: It is important for buildings to be easily identified by common name and street address. Care was taken such that this information is easily read and understood in dark atmospheres during model performance.

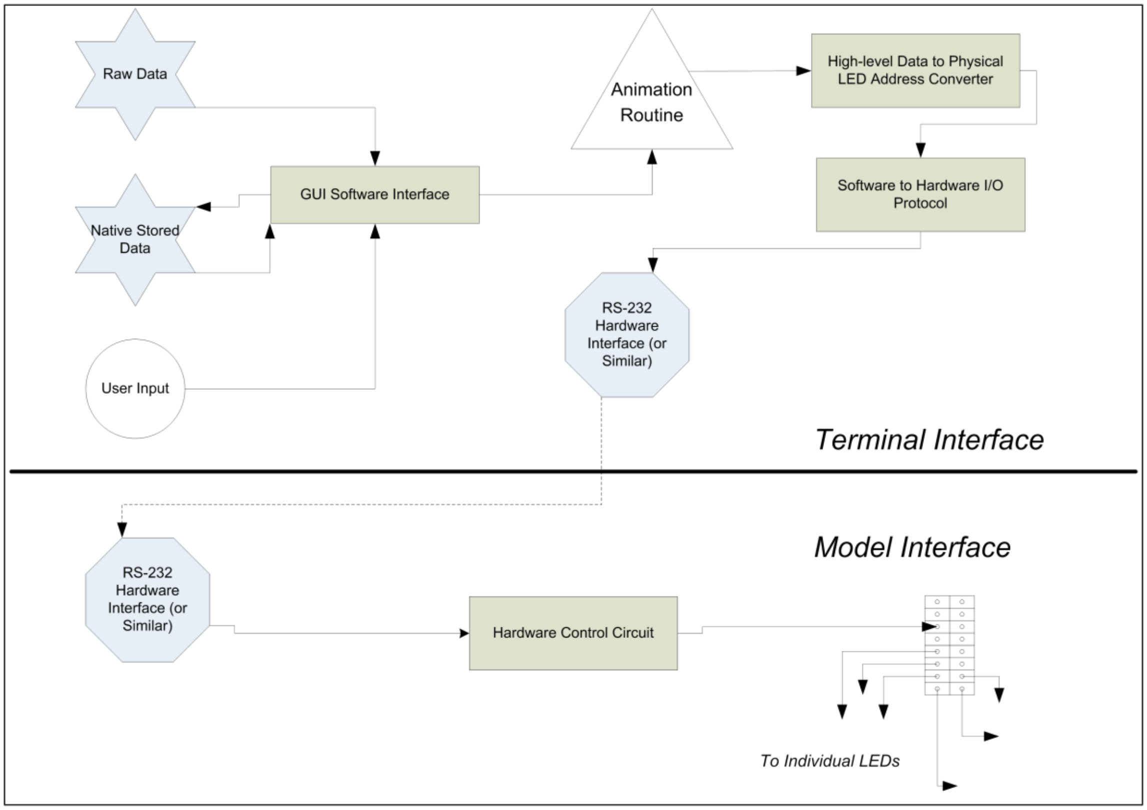

Figure 3: Flowchart Showing Schematic Design of Model Computer Interface

Suggested ways of handling this are either to inscribe, etch, emboss, or otherwise mark the surface of the acrylic street grid with opaque lettering, which when backlit would be easily identified. A second option would require the use of specialized lighting at regular intervals within streets, showing the regular system of addresses along each block.

Modularity: the final model has been developed (figure 5). The model is to be demountable in multiple pieces. A data connection between pieces was devised. The connection is easy to operate, free of loose cables that may be lost during transport, and difficult to damage during shifting. This is why connections employing pin-type connectors were not recommended.

6. Assessing students learning

In the capstone presented here, the learning approach was composed of project based learning combined with continuous discussions between the students, team leaders and the instructor (the instructor is the main author of this paper and the two other authors are the team leaders). Two approaches have been used to evaluate this teaching approach, the direct technique in which students are asked to give their opinion about the course and the indirect way through surveys. The approach we adopted in this particular course and in the architectural engineering education, in general, has been used and refined over years and has proved popular with the vast majority of students over that period. In this course, the students emphasize different aspects of the design process.

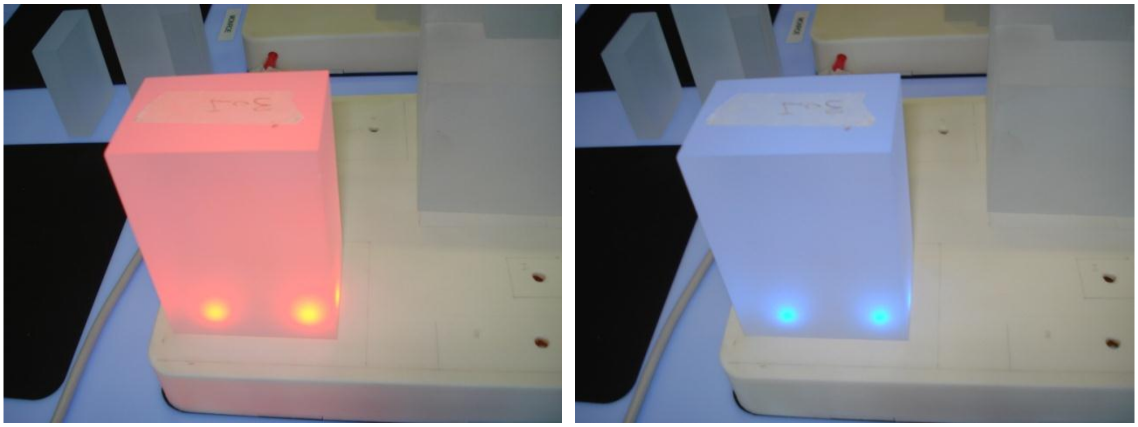

Figure 4: LED illumination testing - several colors (Photo courtesy of Tarek A. Megri)

Figure 5: The final Model (Photo courtesy of Ahmed C. Megri)

The evaluation on how this turned out is based on the instructor and team leaders perception, the work and reports produced by students and the results from student course surveys. Statements in the course evaluation showed that students enjoyed learning and were learning about what they believed to be necessary for future workplaces.

Assessment was made up of a combination of oral and written examination. Towards the end of every semester, the Interprofessional Projects Program organizes an event called IPRO Day, which is a culmination of all the work teams have done during the semester. On that day, all IPRO teams and even guest teams from other universities compete for cash prizes and recognition by giving formal presentations and showcasing their projects in the form of an exhibit. Some of the past guest teams include participants from Auburn University, California State University-Fresno, Michigan Technological University, and more. During the IPRO Day, students have the opportunity to observe other projects and discuss them with their colleagues.

Oral presentations are a common feature of project-based learning courses. The oral presentation assessment scheme is based on: presentation skills, relevance of material, depth of research, comprehension and the response to questions. A weight vary from zero to a maximum number is given for different aspects of the presentation.

Project reports are always used as part of project-based learning. The assessment scheme for a project report is based on: presentation skills (references, language, etc.), methodology and understanding, comprehension, analysis synthesis, organization of ideas, and the content information evaluation, fieldwork, and creativity.

Course surveys were performed periodically twice every semester, mainly to access the feedback from the students. The course questionnaire was used at the end of course in written form. The five parts of the questionnaire related to the student opinions and suggestions for improvements on the performance of faculty, learning objectives, work load, student responsibility and independence for learning and, in the final written evaluation, also about assessment.

Based on assessment, we found in almost all cases that the students performed very well and the reports were of an acceptable quality. We also found that this kind of courses give more freedom to students. This large degree of freedom may result in a sense of insecurity and anxiety, which might lead to some frustration. Apparently, the overall learning approach works out well from the student's point of view, but the balance between freedom and limits is crucial and regular feed-back is important for them to feel confident in this context.

The students are overwhelmingly positive and in general. They identify the course as very different. These students usually complain about the difficulty of starting the project and request more attention from the instructor. Students have ample opportunity to discuss their ideas with the instructor. Extensive time involvement is needed to satisfy some students. Adjustment is needed to meet the expectation of certain category of students.

Based on students' course evaluations, and years of observing the way students learn, I have come to realize that a project-based course is the best way to get students to understand the importance, and necessity, of integrating knowledge from several discipline to produce a final product.

7. Course evaluation:

In parallel with the self-evaluation of each course by the instructor, we also conduct a course evaluation by students. The course objectives introduced earlier in the course are again provided to the students at the end of the semester. The students' input on whether the materials offered have met the objectives is then complied and used in the program outcome assessment process. Results of instructor course evaluations (conducted by students) are reviewed by the Department Chair and the Dean and shared with the faculty.

Each faculty member also conducts an evaluation of performance of students in his/her courses as part of the Program objectives and outcome assessment process. A summary report on the performance of students (to meet the Program objectives) and compliance with the Program outcomes is prepared and submitted to the Department Chair for the assessment purposes. This capstone has been taught twice and further evaluations are needed to reach established conclusions.

Future plans to evaluate the effectiveness of the capstone in term of learning outcomes:

A more rigorous process in assessing the learning outcomes of this capstone course will be implemented, which are in parallel with the Program outcomes. The following outlines process will be used for this capstone course assessment.

- Individual instructor evaluation of the degree of learning achievement of individual students on a capstone team, which includes consideration of the collective achievements of the team.
- Peer evaluation (optional by instructor).
- Grading of deliverables by the instructors (project plan, mid-term review, final report, exhibit (and abstract), oral presentation, team minutes, web site if applicable).
- Teamwork survey.
- Self-assessment.
- Senior Design Symposium judging (with evaluation criteria explicitly indexed to the learning objectives and articulated via rubrics for all measures).

8. Conclusions:

This capstone design was very interesting for students, since they learned integrated approach in which architects and engineering from several disciplines are collaborating to perform a new product using multiple means. Architecture, modeling making, science of materials, lighting reflexion, computer science, electricity are some of the disciplines encounter in this capstone design project. Safety and fire protection, street evacuation are also other disciplines considered in this project. This capstone design has been extremely appreciated by students, so we had to teach this capstone in spring and summer.

Many improvements are considered. For example, while topographically, Downtown Chicago is nearly flat, the area nevertheless has a complex downtown road system that includes 2- and 3-story roadways, as well as numerous operable bridges and rail viaducts. As the multi-level road system is of critical importance to the field of disaster readiness, special consideration must be given to this aspect of the model design.

One option is to physically represent the multi-level streets as multiple levels within the model. However, this strategy is not recommended, as certain streets are nearly completely enclosed by structures, and the upward-shining LED system will be impossible to understand through two-level roads. Also, not having a flat model surface will make transportation difficult.

Recommended, thus, is a special notation and visual organization that clearly indicates the level of roadway in question, but with all road levels physically existing on the same plane. This will require extra care in ensuring that LED lights illuminate solely the roadway in question, without bleed-over and confusion. Similarly, legibility must be given special consideration in such a crowded environment.

Geographic features, such as the Chicago River, Lake Michigan, and Parklands are included in the project as deemed necessary by the project team. If roadways are to be shown on a flat plane then the geographic features shall be created of translucent acrylic of similar thickness to that of the road system, but preferably of a slightly different color. Translucency is important to allow LED arrays below the geographic features to shine through; a color close to white is important so that color shining through is not significantly changed.

Depending on the final design of the model, the street network may require special forms of illumination beyond the regular LED grid discussed in this paper. This may be due, in part, to multiple-level roadways within the downtown. Depending on the display method chosen for these roadways, the streets may require 1) additional LEDs to provide adequate information, and / or 2) extra attention within the base to ensure precision of multiple layers of information within a confined space. The project team members may in fact opt for more specialized equipment solely for use within the street system areas.