

**AC 2009-2488: TEACHING THE INTEGRATION OF SAFETY AND
FIRE-PROTECTION ELEMENTS INTO THE BUILDING DESIGN PROCESS**

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Teaching the integration of safety and fire protection elements into the building design process

Abstract

Summarized within the following article are the attempts made over an eight-year time period at the Illinois Institute of Technology to improve the skills of its Architecture and Architectural Engineering Students with regards to the integration of safety and fire protection into the building design process.

System integration has long been recognized as the key to an effective and efficient building operating building. The process involved in the integration of a fire protection subsystem, along with additional MEP subsystems within a building is quite challenging, and can have a profound impact on the client's satisfaction. This process becomes especially important once further technological system integration within a proposed building is considered in addition to the possibility of future system upgrades and their incorporation into the structure, as newer technologies enter the market place. The objective of this paper is to discuss the project-based learning integrated with formal lectures approach in which the goal is the integration of safety and fire protection measures into the building design process to achieve the most efficient, economical, and environmentally friendly design.

Introduction

Life Safety and Fire protection are an essential part of the MEP design process. This is why safety and fire protection should be considered as an integral part of the Architectural Engineering curriculum and should be addressed early on in the design process.

Architectural Engineering as a single integrated field of study, compared to other engineering disciplines, is in and of itself a multi-disciplined engineering approach. Architectural Engineering includes the design of various building systems including heating, ventilation and air conditioning (HVAC), plumbing, fire protection, electrical, lighting, and structural systems. The Illinois Institute of Technology (IIT) developed an extensive fire protection program comprised of a comprehensive set of courses, including:

Sprinklers, Standpipes, Fire Pumps, Special Suppression and Detection Systems (CAE 422): review and introduction to fluid dynamics applied to sprinklers, standpipes, fire pumps, and special suppression systems; hydraulic design criteria and procedures for sprinklers requirements, standpipes, fire pumps, special suppression systems, and detection and alarm systems using nationally recognized design (National Fire Protection Association) standards, water supply requirement systems and distributions.

Introduction to Fire Dynamic (CAE 424) & Dynamics of Fire (CAE 510): introduction to fire, physics and chemistry, and mass and heat transfer principles, fire fluid mechanic fundamentals, fundamentals and requirements of the burning of materials (gases, liquids, and solids), fire phenomena in enclosures such as pre-flashover and post-flashover.

Fire Protection and Life Safety in Building Design (CAE 425 & CAE 511): fundamentals of building design for fire and life safety. This course emphasize on a systematic design approach, basic considerations of building codes, fire loading, fire resistance, exit design, protective systems, and other fire protection systems.

Computer Fire Modeling Theory and Applications (CAE 426 & CAE 512): introduction to fire heat transfer processes and fire testing materials; application of a set of quantitative engineering tools (fire models) to construct a description of conditions that occur or might occur during the course of a fire; life and structural impacts from hostile fires in buildings.

Design strategies should incorporate safety considerations from the beginning of the design process. This kind of integration requires the architect to be familiar with the specific safety issues of a proposed building, and in many cases prompts the architects to seek information, advice, and knowledge from safety and fire protection consultants at a very early stage. Interaction between the architect and a safety and fire protection consultant can also help with the architectural specification and decision-making. For example, putting the stairway outside the building may help to reduce the risk of smoke inhalation during fire.

The objective of this paper is to discuss the project-based learning integrated with formal lectures approach in which the goal is the integration of safety and fire protection measures into the building design process to achieve the most efficient, economical, and environmentally friendly design.

Course Development of Fire Protection and Life Safety in Building Design (CAE 425 & CAE 511)

A prime objective of the safety and fire protection course (CAE 425 & CAE 511) is to incorporate safety and fire protection in the design process from its inception, starting from the determination of the maximum height and area allowable for each category of building, fire resistance of various components of the building envelope, interior finishes, systems, and finally the design of means of egress. Depending on building type, some or all of the design decisions may affect the design process, including the selection of building height, area, and function of the building, location and size of the stairway, and the composition of the walls. In this course, each student must select a real project, and with the help of mentor from the industry, incorporate safety and fire protection into the design process starting from the conceptual design phase to the design development phase.

Obviously, building codes, such as the IBC code provides safety for all people: residents, employees, staff, and visitors who use the building, but security considerations go far beyond this. A range of different building types -- technically sophisticated facilities -- healthcare facilities, banks, hotels, offices with sensitive data storage areas require multilevel protection. In these cases, protection is not solely for material property, but also for information. In many contemporary facilities, data and data systems rank second in value only to people, and it is vital to remember that data must be protected not only from loss but, perhaps more important, from damage that could lead to "down time" and the financial and institutional chaos that might result.

Building codes regarding ease of egress during fire present another set of issues affecting building safety. The accessibility chapter from IBC 2006 and the Americans with Disabilities Act (ADA) have added yet another regulatory layer. The design strategies that will ensure that a building is both secure and accessible to the disabled need careful planning.

The evidence of past fires indicates that the building design process influences the building's eventual fire safety. Early in 1989, Stollard¹ investigated the human factors in the architectural design process that influence the successful integration of the fire safety objectives with the objectives of architectural design. However, little study has been done regarding the integration of fire protection into design process. Some work has been done on structural^{2,3} and sprinkler⁴ system integration.

In 1989, Fitzgerald⁵ proposed two distinct code approaches: one would maintain the prescriptive code process for developers and architects and a second alternative and integrated performance-based fire safety code. Law⁶ discusses the challenge of integrating fire safety measures into the overall design of a project. In particular, the fire safety strategy must take into account the ways in which the building or installation is to be used, thereby aiming to achieve not only a good standard of fire safety but also better buildings. According to Liew² the key feature for implementing the performance-based fire design codes is the assessment of the fire resistance of the structure. Johann³ introduces recent research and discussed a possible approach to integrating fire safety into the design process for structural framing systems. Hoey⁴ expresses the benefits of using suppression systems as part of an integrated fire safety strategy in a building. It is widely recognized that performance-based codes provide greater advantages over the perspective codes, in term of integration into design process, since it allows designers to use engineering methods to assess the fire safety of the structure. Recently, Megri⁷ discussed the issues of the integration of fire safety and Mechanical, Electrical and Plumbing (MEP) into the design process, starting from the preliminary design phase to the construction phase.

Project Development within CAE 425 & CAE 511 courses

A building code is a set of rules that specifies the minimum acceptable level of safety for buildings and non-building structures. However, designers are expected to challenge those minimum requirements and to implement higher than minimum standard. The main purpose of the building code is to protect public health, safety, and general welfare as they relate to the construction and occupancy of buildings and structures. The building code becomes law of a particular jurisdiction when formally endorsed by the appropriate authority.

This project requires students to develop multiple skills, including the following:

- to be able to understand and use the International Building Code,
- to know when and where specific requirements apply,
- to be able to express their functional understanding in multiple representations including graphs, diagrams, equations, and

- to understand the intent of the code.

Within this course, the students perform a complete project. The steps of the project are described as follow:

- 1) Each student must select an appropriate sized building, and also communicate with the industry to find an appropriate mentor. The instructor intervenes if the student cannot find a project or has difficulty coordinating the project with a mentor. The instructor follows the project with the students, and helps them to find the appropriate solution for problems they have encountered. Students typically encounter problems during this project, such as the interpretation of technical drawings and the integration of the building code (we use IBC) requirements into the design process. The technical drawings are often incomplete and ambiguous, and the symbols used often not universal. There is also no existing CAD software to integrate the code requirements⁴.
- 2) The process of interviewing experts and professional designers is the most effective approach for learning from professional designers and experts in the field. An interview is a conversation with a purpose, and in this instance, this purpose is to gather information from a professional designer. Students are encouraged to arrange multiple meetings with the expert, or experts, in their field of inquiry. Many designers are willing to be interviewed, and are sometimes even flattered by the attention given to their work. The selection of experts is a time-consuming process, and advanced preparation is vital to the selection of the expert as well as the interview itself. Usually the interview can take from one to three hours, and questions should be clear and concise. Students are told to make sure that the person interviewed is willing to be quoted in writing. The students must be flexible enough to allow the interview to go in unexpected directions (usually the areas where the person being interviewed is very knowledgeable). If the interviewee is not able to answer a question, the student needs to proceed to the next questions and get the most benefit from the designer's experience and knowledge. The students are requested to obtain permission to audio-record the interview, and are encouraged to write additional notes immediately after the interview, while the conversation is still fresh in their mind. Students should schedule the interviews after 3 or 4 weeks from the start of the class in order to acquire some background about safety and fire protection that will allow them to ask appropriate, pointed questions and compile the answers into a coherent big picture. It is important that the questions posed to the expert designer be related to his/her specific experience and perspectives, and not general information that could be found from internet, books, or other source of information.
- 3) The project's scope of work that shows the project's codes analysis.
- 4) Building selection: the building can be single use (group A, B, E, F, H, I M, R, S, U), mixed use, or even can be a structure with special requirements, such as covered mall, high-rise building, atrium, underground building, motor vehicle related occupancy, private garage, enclosed parking garage, and so on (Chapters 3 & 4, IBC 2006 edition).

- 5) Identify whether or not there is a proposed change of occupancy for this project. Show previous and proposed occupancies
- 6) Describe the construction type, protected or unprotected, sprinklered or unsprinklered, per Chapter 6, IBC.
- 7) The student must check that the building area, height and number of stories do not exceed the specifications required by the building code. The area of the building is assessed according to IBC Table 503 for new and existing buildings. Building area modification calculations per IBC Section 506 must be illustrated.
- 8) Complete the plans review submittal form (PRSF).
- 9) Fire-ratings: provide the fire ratings for rated assemblies (IBC 1008.1.8.1 thru 1008.3.2), all fire-resistance rated wall enclosures to identify specific ratings and their limits (i.e., smoke partitions, smoke barriers, one, two, four-hour ratings, and 2/3/4-fire walls) (show on life safety plan and all floor plans.). Provide any fire-resistance rated wall, column, beam, floor/ceiling, roof/ceiling assemblies, fire rated head-of-wall joints, curtain walls, and fire stopping penetrations through fire rated construction. Provide details in their entirety, including design illustrations and material specifications (use the UL Directory). Provide a reflected ceiling plan showing lights, diffusers, exit sign, sprinkler heads, smoke detectors and emergency lights, etc.

International Building Code design philosophy is based on a prescriptive approach, such as fire-resistance ratings. The fire-resistance of different building components is evaluated based on a number in units of time. The required time for fire resistance is usually expressed in terms of hours: for example ½ hour, 1 hour, 1 ½ hours. The codes prescribe fire resistance time where members are not allowed to exceed their failure criteria.

The International Building Code requires certain elements of a structure to have fire resistance depending upon size, use of the building, function of the elements, and so on. When exposed to fire, all commonly used structural materials lose some of their strength. For example, concrete can spall, exposing reinforcement. Timber sections deplete by charring. Steel members eventually lose strength. Therefore, according to the prescriptive based philosophy, structural materials must be protected against fire for the required time of fire resistance. Generally, prescriptive approaches are the result of regulation, insurance requirements, and industry practice or company procedures.

The fire resistant based on prescriptive methods is not an ideal solution because these values are determined in a laboratory using a specific structural configuration with a specific size, shape, and specific loads. The time-temperature relationships in the ISO fire do not represent real fires.

- 10) Provide interior finish schedule. Interior finish throughout must be Class A or B. (NFPA 101 10.2 and 16.3.3)

11) Means of egress: This part is addressed by chapter 10 of IBC, 2006. It includes at least the following items:

- Circulation routes including location, type and size of elevators, stairs and ramps.
- Intensive occupant load analysis.
- Number, type and size of exit doors.
- Travel distances to exit doors and areas of refuge.
- Locations, sizes and types of openings in exterior and interior walls.

Building Design Process and the Integration of Safety and Fire Protection

1. Planning/pre-design phase

Every project begins with an idea or a need. The owner will then elicit the services of a registered design professional to perform or assist in the preparation of planning/ pre-design phase activities such as feasibility studies, facilities planning, site analysis, budgeting, or environmental impact analysis. The objective of this phase is to determine whether or not the idea is economically sound and whether the return on investment will satisfactorily cover the projected construction cost, operating expenses, and generate the projected level of revenue. The designer will investigate basic building code and zoning ordinances, and related items through this analysis^{8,11}. This investigation will lead to preliminary design decisions at the project level.

2. Design phase

The design phase consists of four sub-phases:

- conceptual design phase
- schematic design phase
- design development phase
- construction documents and specifications phase

a. Conceptual Design Phase

The designer provides the owner with alternative approaches to the design and construction of the project, adhering to the budget requirements and the owner's desires. The designer prepares various design schemes and a detailed design program listing all the spaces, functions, estimated areas, preferred adjacencies and inter-relationships.

The results will include small-scale preliminary sketches of the overall form of the building, the massing, relationship diagrams, and an outline of the building in relation to the site. A simple sketch of the key sections and elevations may also be included. The designer presents these conceptual drawings to the owner in order to obtain his/her approval of a design scheme for development during the next phase^{10,11}.

While preparing the design schemes, the designer should examine and revise the decisions made during the previous phase and extrapolate the analysis to the building code related issues at building and major space level.

b. Schematic Design Phase

The design scheme selected by the owner is detailed during this phase. The designer begins by identifying the requirements for the building materials and products, for exterior elevation finishes and for structural, mechanical and electrical systems based on the approved design criteria. During this phase, the fire-rating of materials is carefully examined and the codes requirements identified and respected

Based on the design program and overall shape and form, the designer begins to locate and dimension major spaces at an abstract level. This design development is presented to the owner in a form of plans, elevations, sections, renderings, perspectives, 3D models and basic detailing of specific areas. The owner also receives written documents, which provide preliminary project description, outline specifications and cost projections^{9,10,11}. During the schematic design phase, the building code analysis process continues in revising former building design data and checks all design decisions at floor and space level.

Now the real job of MEP integration begins. Decisions must be made as to the location of equipment. Although the schematic drawings are not final, they do reflect the space allowed for the MEP systems (mechanical room, electrical closet, adequate space for a fire pump, etc).

c. Design Development Phase

The design development phase immediately follows approval of the schematic design and any necessary modification to the budget or design program. During this phase, the design is further refined, and detailed plans, sections, elevations and construction details are developed. The designer determines the type and size of equipment, and focuses on technical issues such as constructability and integration of building systems and components. The space layout is then finalized to include its physical characteristics (length, height and depth) and material properties of walls, doors, windows, floor and ceiling. The outline specifications are revised after update of all of these design elements¹¹.

In this phase, the design development drawings are performed; and they indicate all aspects of architectural and structural components of the building. They are the drawings submitted to the contractors for bidding. All MEP systems must be described in sufficient detail so that a reasonable and accurate bid can be made. Before preparing the construction documents, the design must be meticulously checked against locally adopted building code and other design criteria related to circulation, energy, lighting, as well as owner preferences^{9,10}.

The intensive building code checking process covers every building code related item and detail. The design data at this phase is considered almost final. The data includes, but is not limited to: occupancy and construction type of all spaces, construction details that reflect the relation and connection between building materials and components, and layout and height of the building.

d. Construction Documents and Specifications Phase

The construction document and specification phase is considered the final design phase, and it is based on the approved design development documents. The objective of this phase is to provide graphic and written information necessary for bidding, construction and future building management. All the documents produced during this phase, in the form of drawings and specifications, are considered as legal documents and should clearly illustrate the work, rights, duties and responsibilities of all parties involved in the construction process^{9,10,11}.

The designer is obligated to explicitly prove project compliance with various adopted building codes by graphic presentation and written affirmation of the description of every building component or detail related to issues addressed by the building code.

Assessing students learning (courses CAE 425 & CAE 511)

In the course presented here, the learning approach was composed of project based learning combined traditional lectures and exams. 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, at Illinois Institute of Technology has been used and refined over a period of eight 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. Some students might avoid going into detail too much and instead concentrate on solving the problem as a whole. Others focus more on the details of specific part of the design process.

The evaluation on how this turned out is based on the instructor and mentors 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. The final oral presentations are open to all students of the class and from other classes. 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. The full course was concluded with a written report and presentation of the case studies, assessed traditionally by criticism of the oral presentation and report content and form. Guidelines were given in advance.

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 a high 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.

At the end of the semester, a percentage of 95% to 100% of the students finish their project, among them 25% of the projects are qualified to be excellent, 30% are very good, 30% are good and the rest are average. The students are overwhelmingly positive and in general. They identify the course as very different. Every semester a percentage of 5% to 15% of students are against this technique. These students usually complain about the difficulty of starting the project and request more attention from the instructor. The use of dialogue and problem-based learning was found useful in this course when dealing with building code and the integration of the safety and fire protection requirement in the design process.

Conclusions

Teaching students to integrate life safety into the design process has been accomplished through standard lectures, and a real project that the students undertake with the help of mentors from the industry. Students begin their project by consulting the complete set of technical drawings, including the architectural and MEP plans. They are required to check all the international building code requirements in terms of safety and fire protection, encompassing chapters 2 through 11. All details of the project must be explored, and alternative solutions should be discussed and compared. The redundancies are analyzed. Every aspect of the project must be examined and explained. Students consult with the instructor on weekly basis, and are required to submit three progress reports and one final report. Following the submission of each report, the instructor evaluates the student's work and provides pertinent recommendations for future work. The most common difficulty the students encounter during this project includes interpreting and understanding the drawings, since the drawings are frequently incomplete, and the symbols employed are not standard from one project to another. Another common problem encountered is difficulty studying a specific subject, such as a smoke control system. Smoke control is an integral part of the HVAC system and the natural ventilation of the building. Students also find it difficult to identify the distribution of fire rating over the building envelope and structural components in consistent way.

Students have ample opportunity to discuss the integration problems with the instructor as well as with the industrial mentors. During the last week of the semester, each student gives a formal

oral presentation, and the instructor, mentors, as well as the students, are encouraged to ask questions. During that week students have the opportunity to observe other projects and discuss them with their colleagues. The first general conclusion to be drawn is that the learning approach seems to work out well, but we have to respect that this type of learning probably was perceived as very different for the students compared to earlier courses. 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 safety and fire protection into the design process.

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