Chapter 10
Teaching Fire Safety in Schools of Architecture:
The Spanish Case

Juan Bautista Echeverría
https://orcid.org/0000-0002-4438-6449
University of Navarra, Spain

Maria Fernández-Vigil
https://orcid.org/0000-0002-4309-1606
University of Navarra, Spain

ABSTRACT

Fire safety teaching in schools of architecture has become more relevant over the last years in Spain due to the influence that it has in the professional architectural project. The introduction of fire safety knowledge in the intermediate courses of architectural studies has important advantages for the student, who quickly perceives the project as a normative discipline. However, fire safety regulations are complex and difficult to understand for the students. The experience along the last years has progressively evolved from an analysis of the legal documents to a more frequent use of graphical representations. A combination of symbols, diagrams, and simple drawings has proven to be quite effective: Symbols act as anchor repeated throughout the learning process. Diagrams are a first approach to the characteristics of the building. And the simple drawings complete the information so the students can work on the proposed exercise.

INTRODUCTION

Fire Safety (FS) aims to prevent and mitigate the unwanted consequences and effects of fire. The Society of Fire Protection Engineers, an international pioneer institution in the scientific development and dissemination of fire safety, defines Fire Protection Engineering as "the application of engineering principles to prevent and mitigate the unwanted impact of fire" (SFPE, 2018, p. 3). Table 1 contains the technical skills that a fire protection engineer should have according to the same organization (SFPE, 2018, p. 9).

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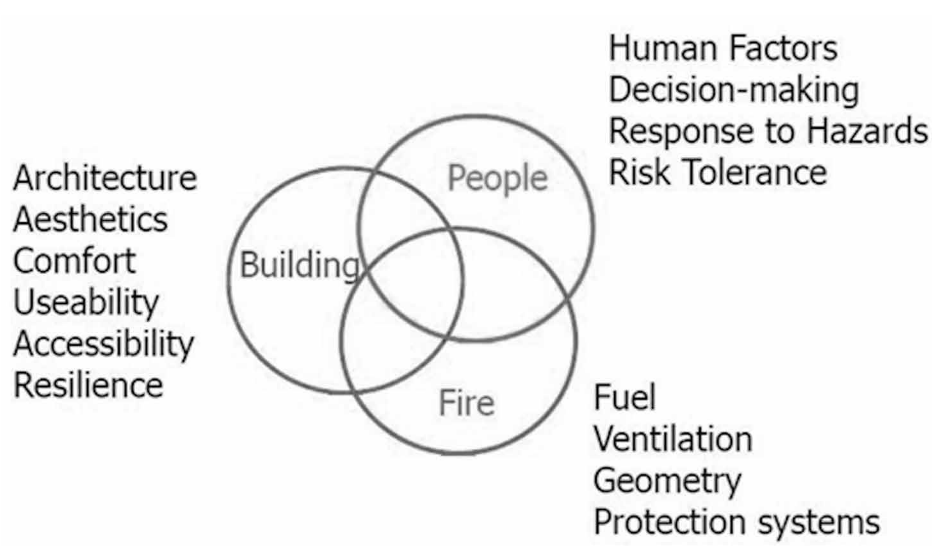
Table 1. Technical competencies and knowledge areas for the professional practice of Fire Protection Engineering, FPE

Minimum Competency	*Fire Science*	*Human Behavior and Evacuation*	*Fire Protection Systems*	*Fire Protection Analysis*
Knowledge Areas	Heat Transfer Fire Chemistry Fire Dynamics	Human Behavior and Physiological Response to Fire Egress and Life Safety Design Concepts	Passive Systems Active Systems Fire Detection and Alarm Fire Suppression	Performance-based Design Smoke Management Evacuation Analysis Structural Fire Protection Risk Management Numerical Methods and Computer Fire Modelling Building and Fire Regulation & Standards

As it can be appreciated, Fire Protection Engineering is a very complex field, which integrates diverse aspects, such as the physics of fire and its performance in buildings, human behavior, or risk analysis. Regarding Fire Safety (FS) in buildings, in which this paper is focused, there is an interaction between the building, its occupants and the destructive fire (Figure 1). This means that predicting how a fire is going to affect a building and its occupants deals with uncertainty and needs very different skills and the use of predictive methods.

Probably because there is an inertia of the traditional role of the Architect in the building process, Architectural education in Spain represents an exception in comparison to other countries. Many technical competencies are required in the university programs, being one of them the capacity to develop safety projects, evacuation, and protection of buildings (Ministry of Education, 2010).

Figure 1. Graphic scheme by B. Meacham
(https://meachamassociates.com)



The objective of this chapter is, therefore, to show the importance of Fire Safety education in the Architects Curriculum Vitae, to present the evolution of the work carried out in two universities along fifteen years, where different teaching methodologies have been implemented, and to evaluate the results of this experience.

FIRE SAFETY REGULATION IN SPAIN

The existing regulation of Fire Safety (FS) in the built environment in Spain, is the Technical Building Code (Código Técnico de la Edificación, CTE, 2006), which was approved in 2006. Previously there were three "Basic Regulations" or "Normative Requirements" (1981, 1991, 1996), the first one being dated back to 1981, that were prescriptive.

The structure of the CTE fire safety regulation establishes an Objective for Fire Safety and develops six Basic Demands, that according to its own text, guarantee the fulfilment of the Objective. These Basic Demands, basically, correspond with the five basic requirements listed in the European Union Product Directive (2011), as shown in Table 2. The only additional need in the Code is the Demand of active Fire Safety Systems, which, to some point, is an additional equipment, and not a performance building characteristic.

Table 2. Relation between the Basic Requirements for Construction Works, Safety in case of fire, in the EU Construction Product Directive and the Needs in the Building Code (CTE)

REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 Basic Requirements in case of fire	*Building Code (CTE) Basic Demands in case of fire*
(a) the load-bearing capacity of the construction can be assumed for a specific period of time	(SI-6) structure load bearing resistance
(b) the generation and spread of fire and smoke within the construction works are limited	(SI-1) Interior spread
(c) the spread of fire to neighbouring construction work is limited	(SI-2) Exterior spread
(d) occupants can leave the construction works or be rescued by other means	(SI-3) Evacuation of occupants
(e) the safety of rescue teams is taken into consideration	(SI-5) Fire service intervention
	(SI-4) Fire Safety systems

The CTE is aligned with the performance-based approach promoted by the most important international organizations related to building codes, such as the Inter-Jurisdictional Regulatory Collaboration Committee (IRCC) or the International Code Council (ICC) (CTE, 2006). This approach allows opening the building activity to more global markets, both to products and professionals.

Performance-Based building regulatory systems set a regulatory framework for the built environment which consists of a performance-based code, acceptable solutions, verification methods, and approved methods of analysis (IRCC, 2010).

Performance-Based codes establish goals, objectives, and functional requirements (in qualitative terms) and allow compliance with them both using acceptable solutions or alternative solutions.

Acceptable solutions have been determined by the authority having jurisdiction (AHJ) to comply with the goals, objectives and functional requirements stated within the regulation. These may be specific prescribed/specified solutions, provided in or referenced by the regulation, or performance-based solutions derived using verification methods provided in or referenced by the regulation.

An Alternative Solution differs, in part or in whole, from the solutions offered by the acceptable solution or verification method but achieves compliance with the requirements of the building regulation to the satisfaction of the AHJ. The designer must adequately justify that the level of performance achieved is, at least, equivalent to the one established in the acceptable solution.

Performance-Based design allows for greater architectural and engineering innovation and could be applicable to solve unusual problems. This may be the case of an airport that requires compartments exceeding the limited surface allowed by the acceptable solutions, or a museum in an existing building that needs a longer travel distance to an EXIT.

The relation between performance-based design and risk has been widely discussed by Meacham (2004, 2005, 2010, 2018, 2021, 2022). As there is a need to assure levels of building performance and risk deemed tolerable to society, risk-informed performance-based design is being explored by different countries to better identify tolerable levels of risk, performance expectations and design criteria.

Many Articles of the Spanish Technical Building Code (CTE) include the term "acceptable levels of risk" as a declaration of intention that risk is a parameter that should be evaluated and quantified. This is the case of Articles 11, 12 and 13, addressing Safety in case of fire, Safety of Use and Accessibility and Healthiness (Table 3).

Table 3. Articles 11 and 13 of the Spanish Building Code (CTE)

Article 11. Basic Demands of Safety in case of fire (SI) The objective of the basic requirement "Safety in case of fire" consists in reducing to **acceptable levels of risk** that the building users suffer damage caused by an accidental fire, because of the characteristics of his project, construction, use and maintenance
Article 12. Basic Demands of Safety of Use and Accessibility (SUA) The objective of the basic requirement "Safety of use and accessibility" consists in reducing to **acceptable levels of risk** that the users suffer immediate damage in the expected use of the buildings, because of the characteristics of his project, construction, use and maintenance, as well as facilitating the access, the nondiscriminatory, independent, and safe use to people with disabilities
Article 13. Basic Demands of Healthiness (HS), "Hygiene, health and environmental protection" The objective of the basic statement "Hygiene, health and environmental protection", treated later under the term of healthiness, consists in reducing to **acceptable levels of risk** that the building users, inside the buildings and under normal using conditions, suffer pains or illness, as well as the **risk** that the buildings become deteriorated or deteriorate the environment or their surroundings, because of the characteristics of his project, construction, use and maintenance

Risk is a well-known science that provides concepts, principles, methods, and models to inform decisions, and can be of big help when addressing building design. Understanding building risks and approaching the design through Performance-Based regulatory systems helps to a better understanding of the regulations as a tool to set minimum standards of quality, more than a way to limit the designer´s freedom.

THE IMPORTANCE OF TEACHING FIRE SAFETY (FS) IN SCHOOLS OF ARCHITECTURE

Fire Safety Education programs around the world have been compiled by the National Fire Protection Association (NFPA, 2022). They are mainly located in North America (US and Canada) and North Europe, and offered by colleges, universities, and institutes with strong engineering background. The content of the programs corresponds very accurately with the knowledge areas described in Table 1.

Teaching Fire Safety (FS) in Schools of Architecture has gained importance in recent years in Spain, as has been pointed by César Martín-Gómez et al. (2014). The reason for it is the significant influence of Fire Safety (FS) in a professional architectural project, since, according to the Spanish Technical Building Code, it affects all the systems of the building (CTE, 2006):

The structural system. The building structure is a key element in the project since it ensures the load-bearing capacity. In case of fire, this load-bearing capacity must be maintained for a determined period of time, to allow the evacuation of the occupants and the intervention of the Fire Brigades. The introduction of a basic knowledge about the behavior of the structure in case of fire (construction materials, functional distribution, resistance, dimensions, etc.) facilitates the integration of the structure in the comprehensive design of the building.

The building envelope system. It allows the indoor-outdoor interaction. The envelope determines the thermal and acoustic performance. In case of fire, the envelope must not contribute to the exterior spread. A basic knowledge about the construction systems, the properties of existing building materials (supporting elements, insulation, waterproofing membranes, green elements…) and their behavior in case of fire allow to increase the awareness of its relevance.

The Compartmentation system. It determines the functional distribution of the building and the dimensions and design of the floorplan. In case of fire, all these aspects must avoid the interior spread. The compartmentation acts as a fire barrier, therefore, it is essential to understand its integrating role that responds to several building requirements.

The interior finishes and coatings system. In case of fire, finishes must not contribute to the interior and exterior spread. Learning about the fire behavior and properties of the materials allows the students to have a more practical and thorough approach.

The building services and facilities system. On the one hand, some building facilities may be a source of origin and spread of fire (kitchens, electrical installations, boilers, etc.). On the other hand, there are building systems specifically designed for controlling and extinguishing the fire (fire extinguishers, detection and alarm devices, sprinklers, firefighting hydrant systems…) In addition to this, it is necessary to have specific enclosures for some of them since they constitute a special risk. The student is expected to foresee the needed equipment (spaces and characteristics) as well as to understand the potential risk of certain facilities in the building and the possibilities of fire control and extinction of the fire protection systems.

In addition, Fire Safety determines technical aspects such as the location of the vertical communication elements (stairs and lifts) or the evacuation routes and the number of exits, in order to ensure a safe evacuation in case of fire. Logically, the design of the evacuation routes also determines the daily movement of people in the building (in non-emergency situations).

To finish, the current legal advances in accessibility cannot be forgotten. In Spain, the accessibility societal goals are established in Law 51/2003 (Jefatura del Estado, 2003) of equality of opportunities, no discrimination and universal accessibility of people with disabilities. Universal accessibility is, therefore, another building objective, developed through functional requirements like lifts, ramps, wide routes, etc. Accessibility requires solutions that can be compatible with evacuation in case of fire, either to the exterior of the building or to safe places inside it. This is one of the biggest challenges in building design today, as the elevators cannot be used for evacuation in many cases and the designer needs to find solutions through horizontal movement to reach safer places, like other compartments or areas of refuge.

All these commented requirements have a big influence in the final characteristics of the building, its materials and construction systems, and should be considered from the initial design stage. The complex and expensive building process makes very difficult to introduce changes once the construction has started.

Building is an increasingly regulated discipline, and this fact influences the academic activity in related areas, such as architecture. Academics frequently question themselves to what extent regulations should be considered as part of the learning content in the Schools of Architecture, as individuals can acquire these skills once they become professionals.

Previous teaching experience demonstrates that a direct academic approach to the building code is counterproductive for the students in order to acquire the required knowledge of construction, building services and integral design of a project. The reasons behind that are the lack of time, personal growth, and work experience of the students.

The Building Code documents and, particularly, the one containing the Fire Safety requirements, are complex and incomprehensible for students. To make it accessible, the legal expressions, definitions and technical vocabulary used need to be explained using simple diagrams or practical examples.

Unless one can tend to think that introducing so much complexity in the design can restrict the students´ imagination, a good integration of the building systems becomes a correct way of stimulating it. By doing this, architectural design approaches his historic role as a discipline, far from a continuous search for the shocking.

Teaching Fire Safety (FS) in the initial or intermediate academic years of Architectural Studies has proven highly beneficial for the students, who quickly understand the architectural project as a regulated discipline, which serves the society through the compliance of essential goals and the establishment of different levels of performance.

THE RELEVANCE OF PERFORMANCE-BASED DESIGN, AND THE POSSIBILITY OF INTRODUCING IT THROUGH FIRE SAFETY

Performance-based design was introduced in the last quarter of the 20th century in some countries in which the excessive increase of prescriptive regulation (wordy, overly theoretical, and often contradictory) was making it considerably difficult to evaluate the building's response to all the regulatory requirements: safety, habitability, and functionality standard levels.

As already pointed, the performance-based regulatory model provides the most advanced and suited approach. As opposed to prescriptive regulations, it allows a real understanding of the behavior of a building and the required comfort and safety levels of its internal and technical systems.

Due to its complexity Fire safety is the perfect discipline to understand the structure of performance-based regulations. In order to predict the behavior of the building in case of fire it is necessary to use predictive models that are indeed very complex. These predictive models are subjected to many uncertain factors, in which the fire (origin and uncertain spread), the human behavior (random or illogical to a certain extent) and the characteristics of the building are interrelated.

Fire Safety performance-based design uses fire scenarios to challenge the building and the occupants´ response, and this is what makes it unique and complex. In comparison with the modern methods and tools used to anticipate energy performance, for example, it is necessary to deal with much more uncertainty.

Innovative Teaching Projects in the Field of Fire Safety (FS)

Due to the usual pedagogic methods in the architectural degree, the students are used to learn through projects, in an essentially graphic way. For that reason, the authors teaching experience throughout the last years has gradually evolved from a detailed and comprehensive explanation of the legislative documents to make them more intelligible for the students, to an increasing use of the graphic techniques and representations.

The use of elaborate drawings, like the ones produced in a professional architecture career, hamper the learning process of the students, who lack the necessary knowledge and time. However, a combination of symbol representations, diagrams, schematic plans, sketches, and simple drawings has proven to be quite effective in this particular case.

Symbols in the representation act as a fixed comprehensive part throughout the learning process. The graphic and schematic plans and diagrams are a first approach to the basic requirements of a building. And the drawings, which combined with the other teaching methods can be very simple, complete the information so the students can acquire the required knowledge and even the skills for their future career as professional architects.

Along the last decade, a set of Innovation Teaching Projects, carried out at the School of Architecture of the University of Navarra, have been introduced to be used in the instruction of fire safety for architecture students. The projects are detailed below:

"Risk-informed Building Systems Design Education, RIBSDE" (academic course 2012-2013)

As it was mentioned before, risk appears as an inseparable parameter of building activity, even in the literal transcription of the Spanish Building Code. Despite its importance, the approach to the regulatory requirements through the concept of risk has not been addressed previously in depth in Schools of Architecture in Spain.

An important transition from a prescriptive regulatory structure to a more risk-informed approach to operations and regulations took place in the United States nuclear industry along 20 years, as discussed by Kadak and Masuo (2007). The plants that used risk in operations showed an improvement in safety, and the key factors were management support, leadership, education, and training in risk principles.

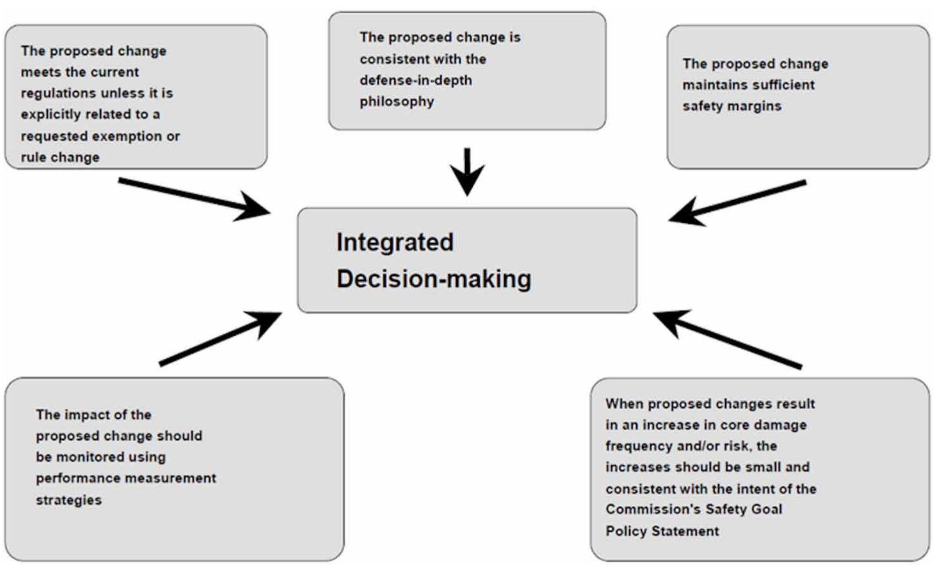
The United States Nuclear Regulatory Commission (NCR, 2020) sets its concept of risk combining the probability of an accident with the consequences of that accident. It examines three questions: What can go wrong? How likely is it? What would be the consequences? And it uses risk information to reduce the probability of an accident and to mitigate its consequences (Table 4).

The terminology "risk-informed performance-based design", included in the current trends in building regulation, refers to a methodology which considers qualitative and quantitative risk information as an input to a decision-making process (Figure 2).

Table 4. The NCR´s Concept of Risk

Probability Consequence	Example	Overall risk
High Probability, High Consequence	An expedition to Mount Everest has a high probability of serious consequences, such as a fatal fall or frozen extremities.	**Very High**
Low Probability, High Consequence	A skydiving accident, in which the parachute fails to open, can also have severe consequences (including fatality). However, the risk is acceptable to many people because using the proper safety precautions can adequately reduce the probability of an accident	**Moderate**
High Probability, Low Consequence	A unicyclist has a relatively high probability of falling. However, the consequences of such an accident are relatively minor. The unicyclist usually lands on his or her feet or, at worst, takes a tumble. Thus, even though the probability of falling is high, the consequences are so minor that the overall risk is low	**Low**

Figure 2. Graphic scheme which depicts the principles of Risk-Informed Decision-making process, by United States Nuclear Regulatory Commission
(https://www.nrc.gov/)



That process integrates, in addition to the traditional risk parameters (damage probability and consequences), follow-up and monitoring mechanisms, perception and other sociological aspects. The person, in this case the architect, who makes the decisions, must know the cost and repercussions of them, as well as how to evaluate these decisions, in order to integrate them into a permanent process.

This educational project (Table 5) successfully used the concept of risk to introduce the basic knowledge on building services.

The obtained results can be summarized in three ideas:

Table 5. Structure of the course divided in lectures and contents related to risk-informed performance-based fire protection design for students of Architecture

Contents of the subject "Fire Safety in Buildings"	
Session 1: Introduction	**Risk** Associated with building Fire Safety
Session 2: Interior Spread	**Uncertainty** associated with interior fire spread (Compartmentalization, lifts)
Session 3: Interior Spread	**Uncertainty** associated with interior fire spread (Special risk zones and locals, reaction to fire, passes through compartmentalization)
Session 4: Exterior Spread	**Uncertainty** associated with exterior spread (facades, materials)
Session 5: Evacuation	**Uncertainty** associated with human behavior and building evacuation (Exits, routes)
Session 6: Accessibility	**Uncertainty** associated with the use of buildings by people with disabilities
Session 7: Fire Protection Systems	**Uncertainty** associated with fire protection systems
Session 8: Fire Protection Systems	**Uncertainty** associated with fire protection systems (design, reliability, maintenance)
Session 9: Fire Department Operation	**Uncertainty** associated with the fire department operation (resistance, access)
Session 10: Structure Fire Resistance	**Uncertainty** associated with the load bearing capacity of the structure in case of fire (concrete, steel, wood)

1. Better understanding by the students of the building regulations related to the facilities. This will contribute to the better training of the architects, both those who will have their own professional practice, as well as those who will work for public administrations.
2. The students acquire a cautious awareness of the professional practice, in which certain building pathologies are recurrently present, especially during the first years of practice.
3. Promotion of University research in innovative aspects, creating quantitative and not merely speculative results.

"Development of a graphical method for teaching Fire Safety in the built environment" (academic course 2013-2014)

This educational project analyzed the importance of the drawing techniques to teach Fire Safety engineering. The dynamic required a previous planning effort from the teachers, as well as coherence in the representation since the student must be able to read the statements unequivocally. This task is not always easy, due to problems of scale, amount of information and representation.

For that reason, the project developed learning material based on a combination of drawings, diagrams, and symbols easily comprehensible by the students. Figure 3 shows the evolution of the graphical representation of the same exercise along three courses.

In Figure 4, the graphical method developed in this project can be appreciated: on the left (red box) there are simple drawings with all the needed information about the building. In the middle of the figure (green box), there are the diagrams, where the student can quickly recognize the characteristics of the building, such as the uses and its location. And finally, on the right (blue box) there are the symbols, which are present in every exercise, providing the same representation language for all, both students and professors.

Figure 3. Graphical evolution of the exercises

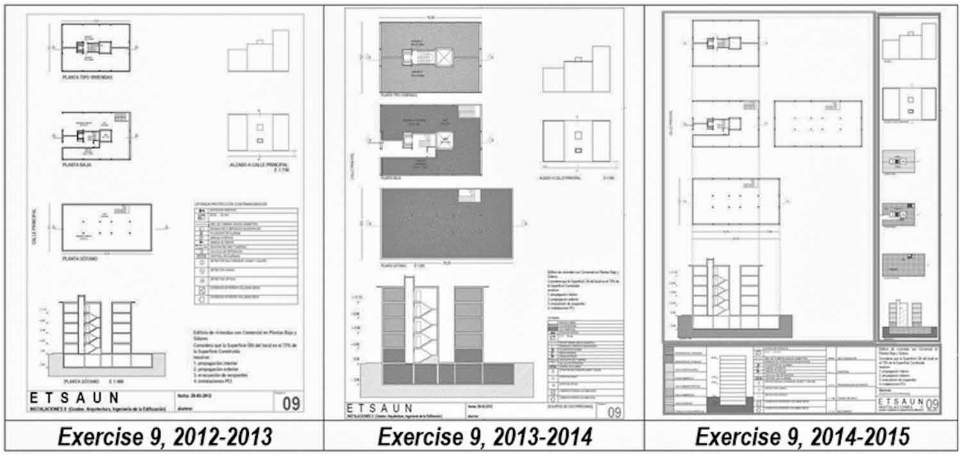
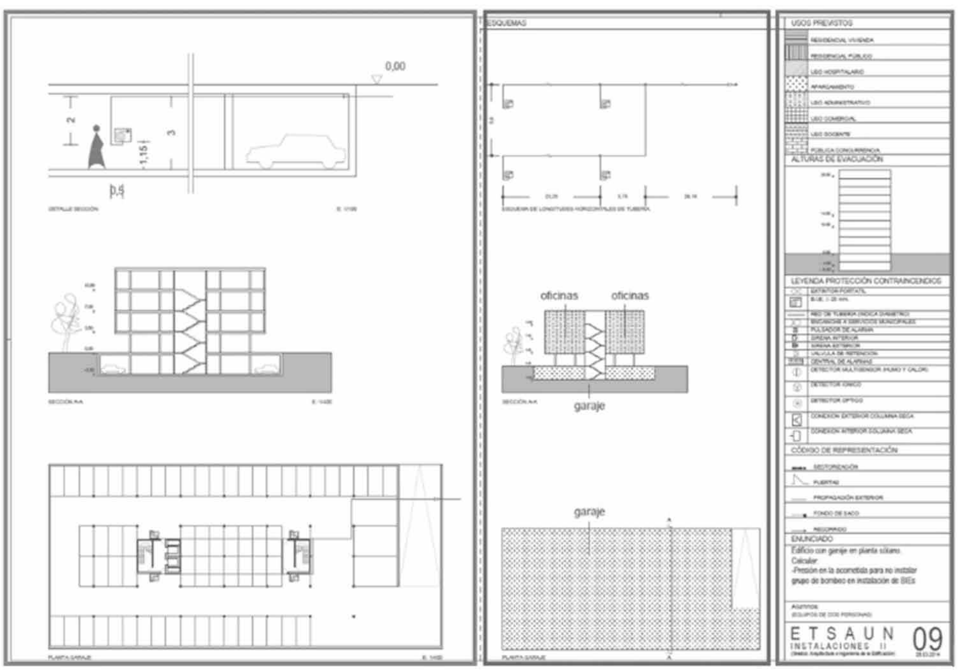


Figure 4. Example of one exercise using the graphical method developed

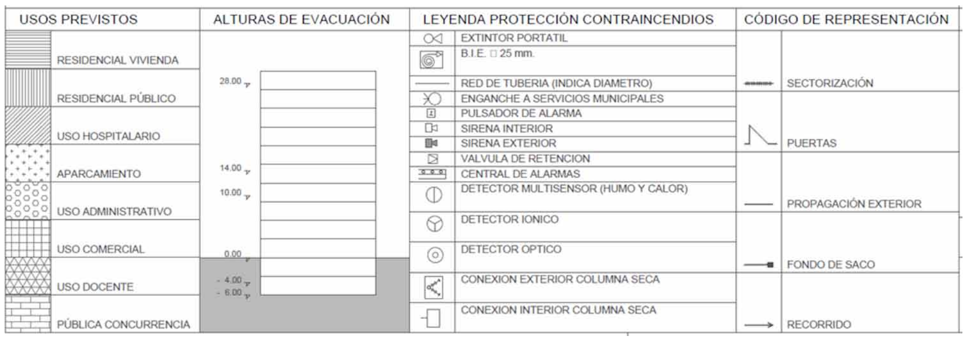


The symbols are shown in detail in Figure 5. They are divided in four categories:

1. Uses. Characterize the building risk, and the regulations require for them different levels of safety.
2. Evacuation heights. Characterize the building risk associated to the occupants´ evacuation and the Fire Service operation
3. Fire safety systems. Complete the Fire Safety strategy in an active way.

4. Representation of construction elements. Restricted to very few important elements (compartments, doors, fire spread and evacuation routes).

Figure 5. Detail of the symbols used in the new graphical method. The different uses of the building, evacuation heights, fire protection systems and a representation code are included



The result of this project can be summarized in two ideas:

1. Development of a graphical method for weekly exercises and exams of the course.
2. Definition of the structure and elements of this graphical method as a combination of:
   i. **Symbols**. They are present in all the representations, resulting in a connecting and guiding graphical element that facilitates learning and understanding.
   ii. **Diagrams or Schematic plans**. This type of representation increases the agility and clarity of the recognition process of the geometric characteristics of the building (volume, functional distribution, floorplans, circulation elements…). This simplified representation includes the building envelope and the main integrating elements (horizontal and vertical circulation such as the staircase, corridors or lifts, etc.).
   iii Simple drawings. The previous steps ensure a basic understanding of the building and can be followed by a simple geometrical definition that introduces some technical information.

"From Drawing to Scheme: optimization of the graphic exchange for Fire Safety teaching using basic digital representation tools (such as Microsoft Paint and Paintbrush for macOS)" (academic course 2020-2021)

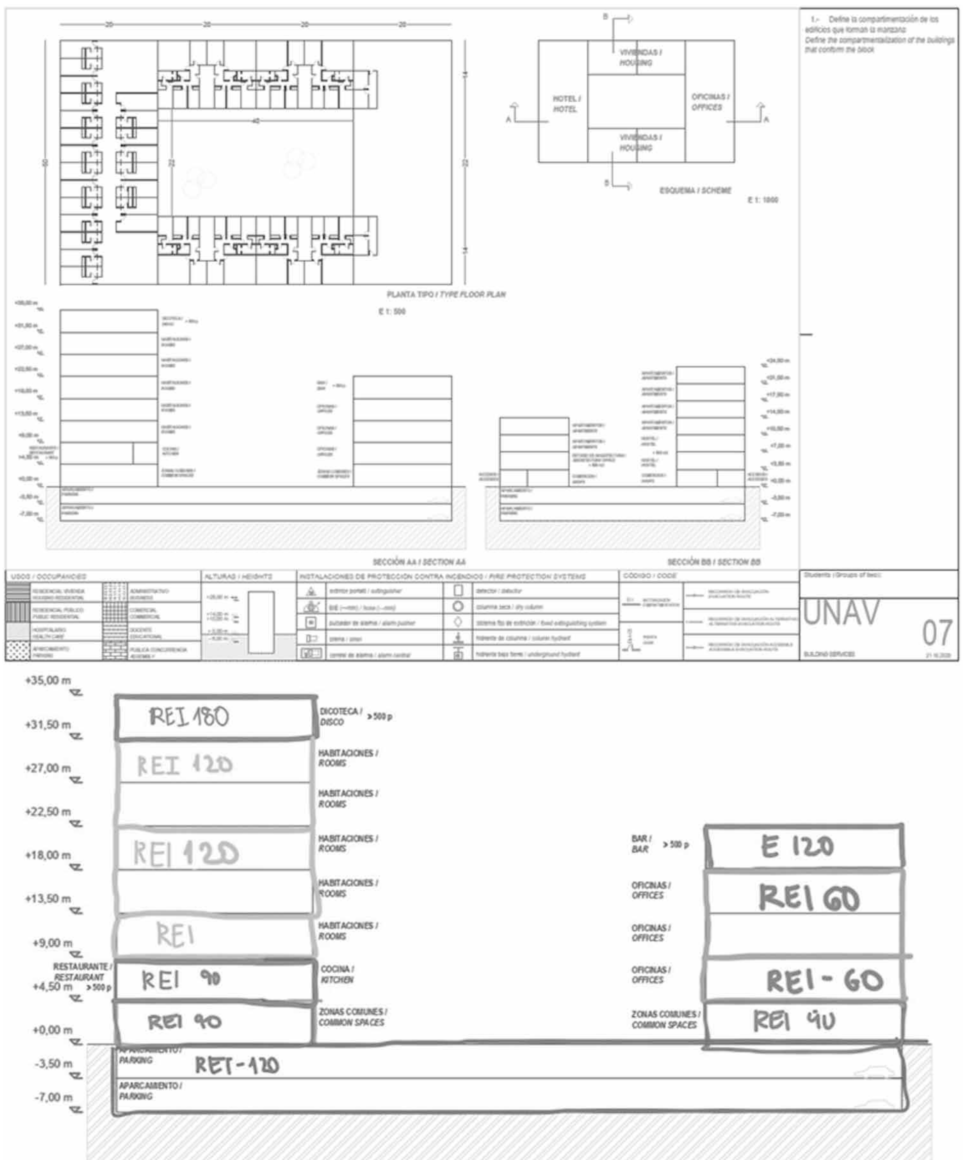
This educational project was adapted under the circumstances caused by the Covid-19 pandemic. The aim of the project is to facilitate the information sharing between teachers and students using basic digital tools and software.

The situation caused by the Covid-19 forces the Universities to think about the reality of a totally flexible teaching, ranging from 100% conventional face-to-face learning to 100% online. This fact represents an unprecedented challenge for architectural teaching, since it is developed in a fundamentally graphic environment. The key factors identified for this urgent transformation are as follows:

1. Use of simple (requiring practically no prior learning), universal (accessible to all students in any device), and intuitive computer tools.
2. Work with simple and lightweight files that allow integration with other universal files (such as *png, *jpg, *gif, etc. image files).
3. Ease of work on the files by another user, such as teacher correction.

Figure 6 shows the exercise facilitated to the students and his completion using the digital tools.

Figure 6. Example of an exercise and the solution using simple digital tools.



The results of the project can be summarized in the following ideas:

1. To generate a methodology starting from the use of the tools.
2. Reduction of the time spent in drawing and graphic representation, dedicating more time to the design, analysis and thinking process.
3. Less complexity: Optimization of the exchange of documentation (teacher-student and between students). That is encouraged by the interaction of drawing tools with the most universal image files.
4. Facilitate the "learning by doing" method.
5. Formulation of an educational methodology from this teaching experience which facilitates learning and interaction with students.

A satisfaction survey was conducted at the end of the course, in which the student was asked about the new learning process. 100% (n = 50) of the students considered that the weekly exercises were useful in order to learn and understand the subject.

When they were asked about the digital tools used, 90% (n = 45) answered word texts, 86% (n = 43) answered excel sheets, and 82% (n = 41) answered digital images obtained with simple tools such as paint or drawings in tablets. Only 4% (n = 2) of the students stated that they did not use digital tools.

BOOK FOR THE STUDENTS

As a result of the first ten years of the Fire Safety teaching experience, the authors had the opportunity of writing a book for their students (Echeverría et al., 2016). It develops the philosophy of translating a quite complex problem, as described in the Introduction, into a more accessible knowledge for young architecture students. The first idea behind its structure is to approach the problem in a completely different way than the offered by the official code documents. Table 6 contains the index of the book, divided in 5 chapters.

The Fundamentals become important to understand aspects of fire science, like how fire starts in a room, how do materials collaborate to its spread, heat, smoke, or people movement. Big importance has been given to translate quite complex ideas into simple drawings or schemes.

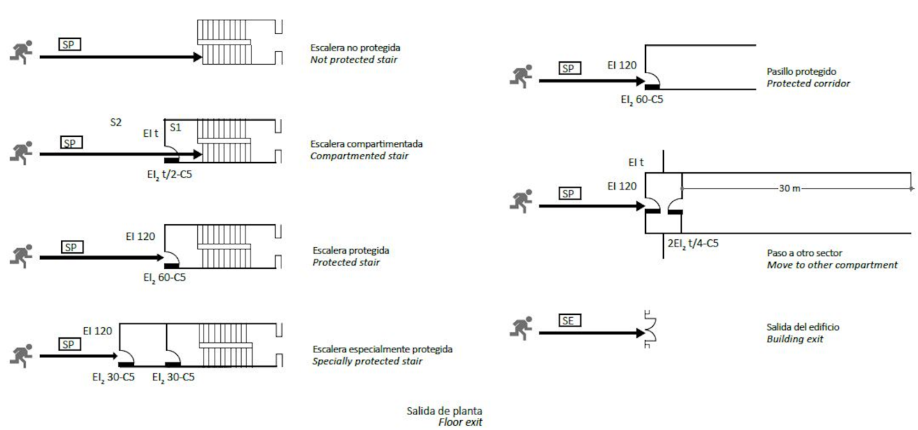
As an example, the Building Code offers a description of 338 words for Floor Exit, this being one of the critical definitions to understand the characteristics of a building evacuation. In addition, the definition itself is hard to understand, even for professionals with years of experience. The scheme in the book (Figure 7) represents the seven possibilities of arriving to geographical points in the building, depending on its type, that the code characterizes as safe enough as to conclude the evacuation route length.

Fire protection systems are not a characteristic of the building, as commented before, but the students need to understand how they do work, and not only their number or distribution in the building. Talking about sprinklers, for example, is a way of introducing their high effectiveness, the fact that protecting a commercial space or a tall building is almost impossible without them, or that they become very convenient in hotels.

Table 6. Index of the book "Seguridad en caso de incendio para diseñadores de edificios-Fire Safety for Building Designers"

Fundamentals	What is fire? / Flammability / Fuel Load Density / Weighted and corrected Fuel Load Density /Heat Release Rate/ Smoke / Fire Resistance / Reaction to Fire / Occupancy / Evacuation Origin / Evacuation Route / Stairs / Corridors and Ramps / Floor Exit / Evacuation Speed / Evacuation Flow
Fire Protection Systems	Detection and Alarm / Fire Suppression Water Supply Systems / Hydrants / Extinguishers / Hoses / Dry column / Sprinklers
Normative requirements	Fire Safety. Goals, Objectives, and Basic Demands **Fire Safety 1: Interior Spread**. Compartmentation **Fire Safety 1: Interior Spread**. Special Risk locals **Fire Safety 1: Interior Spread**. Passes through compartmentation **Fire Safety 1: Interior Spread**. Reaction to fire **Fire Safety 2: Exterior Spread**. Dividing Walls and Facades **Fire Safety 2: Exterior Spread**. Roofs **Fire Safety 3**: **Evacuation of Occupants**. Compatibility between Evacuation Elements **Fire Safety 3**: **Evacuation of Occupants**. Number of Exits and Travel Distances **Fire Safety 3: Evacuation of Occupants**. Dimensioning of the Evacuation Elements / **Fire Safety 3: Evacuation of Occupants**. Capacity and type of the Evacuation Stairs **Fire Safety 3: Evacuation of Occupants**. People with disabilities **Fire Safety 4**: Fire Protection Systems **Fire Safety 5**: Fire Department Operation **Fire Safety 6**: Structure Fire Resistance Safety of Use and Accessibility. Goals, Objectives, and Basic Demands **Safety of Use and Accessibility 1**: Stairs **Safety of Use and Accessibility 4**: Inappropriate lighting **Safety of Use and Accessibility 9**: Accessibility
Case Studies	Single family house / Housing block: 4 stories / Housing block: 6 stories / Housing block: tower / Parking / Hotel / Offices: 6 stories / Office: tower / Commercial mall / Hospital /Assembly occupancy: museum
Annexes	Symbology / Terms / Uses / Bibliography

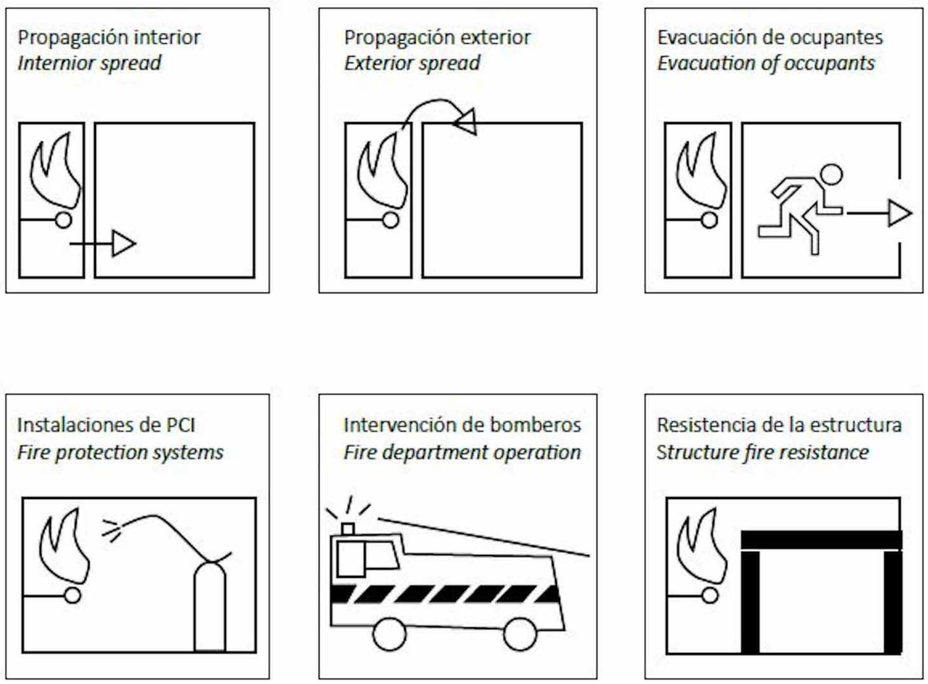
Figure 7. Drawing summarizing the definition of Floor Exit



Normative requirements are approached giving big importance to the fact that the Spanish code is performance oriented. This offers a possibility to extend the idea amongst the students that designing alternative solutions than the one offered by the deem to satisfy solutions in the Basic Documents is not only an opportunity in Fire Safety, but in every building requirement. Understanding the pyramidal structure of Performance-Based codes (IRCC, 2010): Goals, Objectives and Functional Requirements is a basic point of departure to understand what is really demanded by the regulations.

Symbology plays an important role also when approaching the regulations. The symbols representing the six Fire Safety Demands in the code, repeated in every presentation when referring to them, act as an anchor to the students. They have been represented in a functional way, as to enhance the importance of the functional requirements in a performance-based code (Figure 8).

Figure 8. Graphic Symbols for the Fire Safety Basic Demands in the Spanish Building Code



Case studies are important because many buildings have a form and distribution that derives from a rationality behind them. For example, a tower of offices is a ring of workspace surrounding a nucleus of communications (stairs, elevators, etc.) and services (restrooms, ducts, etc.). Of course, it is not compulsory to have such a distribution, but the clients´ requirements tend to optimize the naturally lighted workspace.

Some Annexes complete the book. The symbology of fire safety systems, emergency lighting, compartmentalization and evacuation routes, a core universal representation of an Evacuation Plan. A list of important Fire Safety terms contained in ISO 13943 (2018). And a list of the uses in the Code compared to the ones in NFPA 101 (2021).

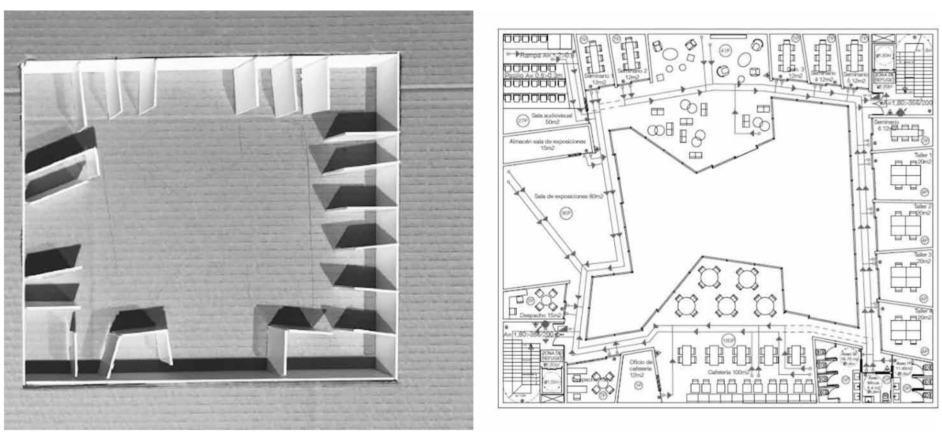
PROJECT-BASED LEARNING EXPERIENCE INTRODUCING FIRE SAFETY

The practice of the authors has evolved from very simple exercises to more complex ones. Along the last years, they have introduced Fire Safety design in collaboration with the Design Studio in the second course of the Architectural Degree. This means that the students are about twenty years old and are in the first steps of their instruction in the whole design process.

An integration project (including fire safety and other areas, like construction or structural design) is proposed by a group of academics, leaded by the Design Studio professors. The proposed buildings at this stage are never too big and complex, considering the level of the students, but the degree of development required is the one of professional projects presented for licensing.

The students are given a building program, that includes spaces and rooms for building services (electricity, HVAC, heating, and cooling production, etc.), stairs, ramps, evacuation routes, emergency EXITS, etc. In the case of Fire Safety, they are required to elaborate two families of floor plans and a complete report. The first family of floor plans is a representation of the fire spread challenge, including the compartments and their fire resistance, the materials, and their reaction to fire and the structure and its load bearing capacity. The second family of floor plans is a representation of the evacuation routes and fire safety systems as presented in Figure 9.

Figure 9. Project for a University Center. University of Navarra, course 2020-2021. Student Marta Idoate



The period given to the students to develop the full project is about three or four weeks, and they are required to present sketches very quicky, not having too much time to think about different options, being forced to make agile decisions based on the Fire Safety requirements, like the number of stairs and EXITS and the travel lengths to them.

Contrary to what might initially seem, the results show very clearly that working with regulatory impositions help the students to make quick decisions and once they have set the initial map, using Gombrich terminology (1982), they can use the rest of the time to develop in depth their proposals.

GENERAL SATISFACTION SURVEYS

Regarding the whole teaching experience of the subject "Fire Safety in the built environment", along several years satisfaction surveys have been conducted, both in the University San Pablo CEU (from 2006 to 2014) and in the University of Navarra (from 2014 to 2022).

The surveys from both institutions have been considered separately, as their methodology and ratings differ. The method used in the University San Pablo-CEU considers a 1-10 numerical rating. The one used in the University of Navarra considers a 1-5 degree of satisfaction and has been translated into a 1-10 rating multiplying the results by 2.

Table 7 and Table 8 reflect the results and the number of surveys per year. A total number of 588 surveys has been conducted at the two universities.

Table 7. Satisfaction Surveys at University San Pablo-CEU

Academic course	*Rating (0-10)*	*Number of surveys*
2006-2007	*8,7*	*59*
2007-2008	*3,38*	*40*
2008-2009	*8,93*	*52*
2009-2010	*9,24*	*29*
2010-2011	*9,19*	*14*
2011-2012	*10*	*9*
2012-2013 (*)	*8,47*	*21*
2013-2014 (**)	*9,23*	*13*
	8,98 (average)	***237 (total)***
(*) "Risk-informed Building Systems Design Education, RIBSDE" ***(**) "Development of a graphical method for teaching Fire Safety in the built environment"***		

Table 8. Satisfaction Surveys at University of Navarra

Academic course	*Rating (0-10)*	*Number of surveys*
2014-2015	*8,34*	*41*
2015-2016	*7,76*	*42*
2016-2017	*8*	*46*
2017-2018	*7,9*	*80*
2018-2019	*8,43*	*37*
No survey in 2019-2020		
2020-2021 (***)	*8,72*	*50*
2021-2022	*9*	*55*
	8,31 (average)	***351 (total)***
(***) "From Drawing to Scheme: optimization of the graphic exchange for Fire Safety teaching using basic digital representation tools (such as Microsoft Paint and Paintbrush for macOS)"		

Figure 10 and Figure 11 show the evolution of the surveys in both institutions and the line of tendency. Despite certain fluctuations, which are unavoidable in this kind of evaluation that depends on multiple factors, the tendency line is ascendant. It seems clear that the students are generally pleased with the development of the course, and their satisfaction level has grown over the years.

Figure 10. Evolution of surveys results per year. University San Pablo-CEU

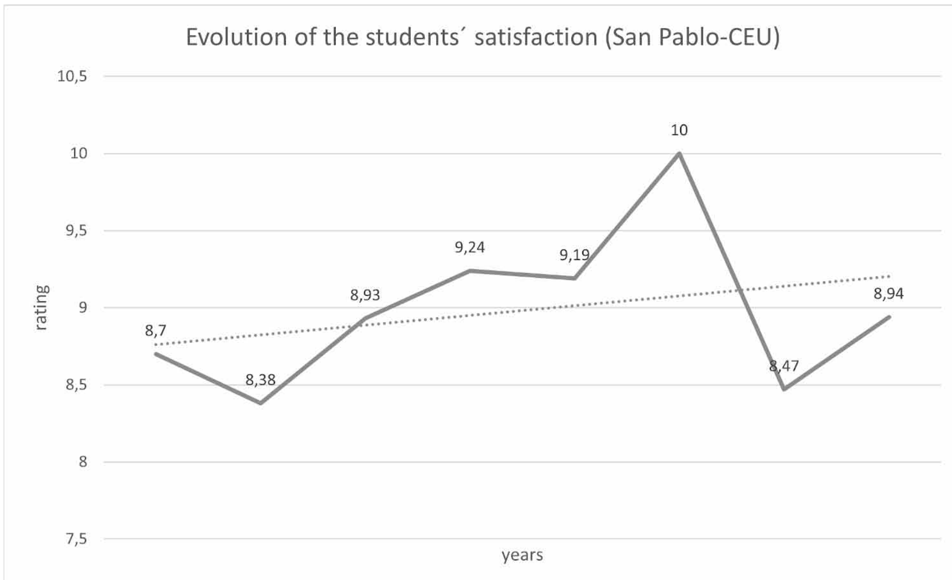
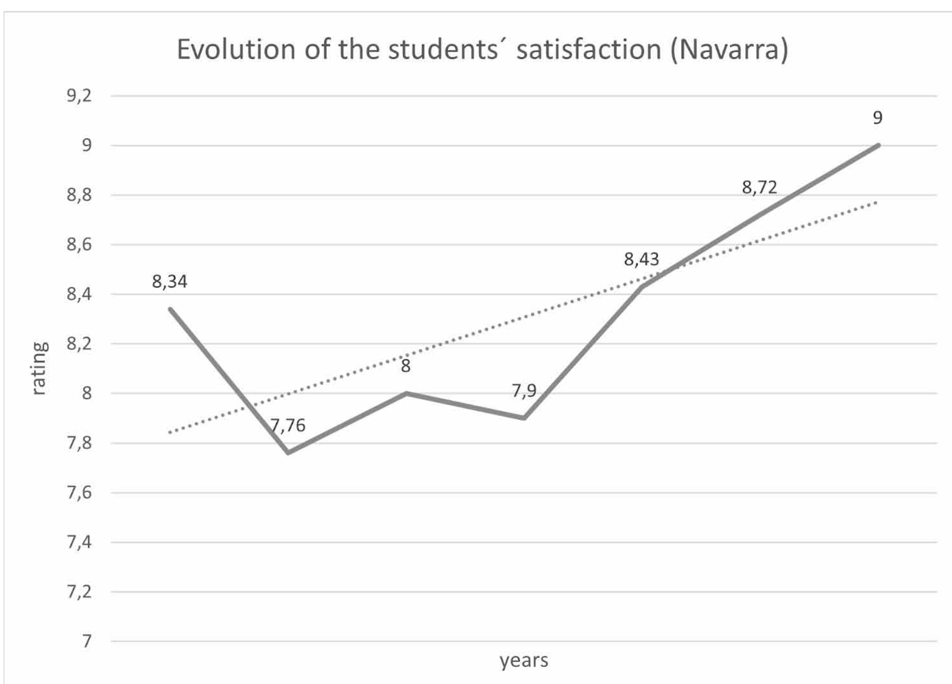


Figure 11. Evolution of surveys results per year. University of Navarra



CONCLUSION

Fire protection engineering (Fire Safety) is becoming a basic academic discipline in the Schools of Architecture. This is especially important in Spain, where the official university program includes the competency to develop safety projects, evacuation, and protection of buildings.

Risk associated to Fire Safety, helps the students to understand, widely, Building Regulations and, specifically, Performance-based regulatory systems. Understanding societal goals and functional requirements approaches the importance of building performance.

The prescriptive parts of the building codes are hardly understandable for the students of architecture. This is particularly evident in the case of Fire Safety. Approaching prescriptions through performance and translating complex definitions into simple schemes makes it easier for them.

Representation plays a decisive role in teaching Fire Safety, being a potential way to promote critical reflection on the characteristics of the built-up areas and urban environment. It is also the language used for information exchange between teachers and students in the architectural learning process.

The experience throughout the years has shown that teaching Fire Safety has a positive impact on the students that goes beyond the actual specific knowledge on the subject. Two big advantages for the students can be pointed. The first one is the fact of understanding architectural design as a regulated discipline and a service to the society, more than the simple result of whim. This philosophy, far from limiting the student imagination, puts the basis for sane creativity. The second one is that introducing the students to performance-based design is an appropriate way to understand how the buildings do work and their performance. Understanding their behavior under different scenarios helps to meet the regulation requirements to ensure the adequate quality.

FUTURE RESEARCH DIRECTIONS

Expanding STEM education, a need for the countries that need to face a complex future, will take advantage of the fields where theoretical and practical knowledge meet. Teaching Fire Safety in Schools of Architecture is a novel discipline but has demonstrated to be useful as a part of a holistic building design education.

The experiences shown in this chapter invite to strengthen the relation between technical knowledge and graphic education for future architects. This is especially important as new graphic representation and communication tools are widely extended.

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KEY TERMS AND DEFINITIONS

Acceptable Solution (Approved Document, Deemed to Comply): A solution that has been determined by the authority having jurisdiction (AHJ) to comply with the societal goals, functional objectives and performance requirements stated within a performance-based regulation. These may be specific prescribed/specified solutions, provided in or referenced by the regulation, or performance-based solutions derived using verification methods provided in or referenced by the regulation.

Alternative Solutions: A solution that differs, in part or in whole, from the solutions offered by the acceptable solution or verification method but achieves compliance with the performance requirements of the building regulation to the satisfaction of the AHJ.

Descriptive (Prescriptive) Requirement: A requirement expressed using definitions, particular (product) types or classes, or design features.

Functional Objective: A statement of how a building or its systems function to meet a societal goal for the building.

Functional Requirement: A requirement expressed using only qualitative terms and stating a goal or objective which shall be achieved (e.g., "buildings shall have escape routes which allow users to leave the building sufficiently quickly and safely, taking into consideration its purpose and size, and whether emergency equipment can be used").

Objective: Goal or objectives the building must achieve.

Performance-Based: Being described in terms of the performance of a material, product, component or system which can be measured, calculated, or predicted.

Performance-Based Building Regulatory System: A regulatory framework for the built environment which consists of 1) a performance-based regulation (code), 2) acceptable solutions, 3) verification methods, and approved methods of analysis.

Prescriptive-Based (Specification): Being prescribed or specified in terms of dimensions, materials installation, or operation.

Risk-Informed: Method or technique which considers qualitative and quantitative risk.